

The idea and procedure for its verification on the example of a new environment friendly reusable multipurpose composite material based on used chip board furniture and plastics

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Abstract

Each year thousands of tons wood based furniture including scrapped particle board and panels end their lives being thrown away by their users. At present there is no effective method for utilizing such waste other than dumping in landfills or incineration. This however means more space on landfills needed for storage of waste or contributes to the global warming by generating carbon dioxide and multitudes of potentially harmful substances released while combusting plates painted with different lacquers and surface varnishes. In parallel, plastics such as ABS used in desktop computers, screens and peripherals pose another challenge for recyclers.

The proposed process is environmentally friendly as no chemical compounds needs to be added to activate and control it. The early experiments with this new composite material confirmed on its expected physical and mechanical characteristics. It is further foreseen this new composite material will be further recycled as it reaches the end of life time.

1. Combining process

1.1 Characterization of the combining process from the theoretical perspective

Composites are the most common way of new materials elaboration. Among them polymeric systems give very broad possibilities to form new materials with polymer as a matrix and many different kinds of additives. In the literature there are many attempts to define composites [1-4]. In the most common opinion composites are defined as at least two component systems with properties different than constituents' properties. Components forming composites are mutually not miscible and they preserve their boundaries, distinct shapes and

properties in microscopic scale. At the contrary polymeric mixes (blends), depending on mutual miscibility, may form system without defined boundaries between components [4,5]. But in the case when polymers are not mutually miscible the difference between polymer blends and polymer composites is not precisely defined. Dispersing component, in most cases with higher volume content, is called "matrix". Component dispersed in matrix is called "reinforcement". Composites are also frequently produced in recycling processes [6]. For us the most interesting is a class of polymer composites called "filled polymers". In filled polymers small reinforcement solid particles are introduced into polymeric matrix and evenly dispersed. This kind of reinforcement is called "filler".

When polymer matrixes are collected for recycling purposes two cases are possible. In the first case polymeric materials are collected by processor (own recyclable material) and filling process is performed as for virgin plastics. In the second case plastics are collected from municipal solid wastes or industrial wastes. In this situation filling process is much more complicated because of practical impossibility of precise plastics segregation and impurities elimination [6,7]. Even more difficult is situation when both matrix material and filler particles are obtained from recycling processes as in the our case.

1.2 Basic factors determining composites combining and properties

Two main properties classes are important for all polymer materials: processing properties (mainly rheological and thermodynamic) and performance properties (mechanical, electrical, thermal, optical, wear etc.). As was stated earlier composite's properties are different from properties exhibited by matrix, in this case by polymeric matrix, and properties of reinforcement. The simplest theory (frequently called "mixture theory") defines composite properties as proportional to components content.

In the case of two component composites it gives:

$$P = \varphi \cdot P_A + (1 - \varphi) \cdot P_B \quad (1)$$

where: P – given property of composite, P_A, P_B – the same property of first and second component respectively, φ – volumetric concentration of first component.

For multicomponent composites analogous equations are formulated. Properties of real composite materials are not simple resultant of components characteristics. Three main factors determine final properties of multicomponent polymeric systems:

- Polymer matrix properties;
- Reinforcement properties;
- Interactions taking place at the interface between matrix and reinforcement.

1.3 Polymer matrix significance

Polymer matrix nature and properties is one of deciding factors influencing ready composites features. Depending on filler content and nature, matrix properties are retained in lesser or bigger extend in filled polymer. When filler contribution is low (in the case of nano-composites very low) matrix properties are only slightly modified. In many cases fillers are added to alter one property with intention not to alter all others. For example pigments and colorants are added to change only colour of polymer. With high levels of filler content quite different materials can be produced.

Taking into account recyclability very important are processing properties. Thermoplastic matrixes constitute composites capable of numerous forming processes. These materials can be recycled many times. But into consideration must be taken that every processing procedure deteriorate polymer properties. In many industry branches recyclates are forbidden because of properties deterioration and impurities presence (optics, medicine). Thermosetting materials can be processed only once. In the following recycling processes thermosetting materials are usually powdered and used as filler added to another thermoplastic polymer. Polymers planned to recycle in the present project (ABS, PE, PP, PS) are thermoplastic. They can be used as matrixes in proposed filling recycling processes. Furniture boards with wood as main component are not thermoplastic. Polymers used in furniture boards production are thermosetting in their nature [7-10]. Frequently applied are melamine, formaldehyde, phenolic and urea resins. So the only possibility to recycle these products together with thermoplastic polymers is to grind them and apply as polymer filler.

For the process of filler combining with polymer very important are rheological properties of the matrix [4, 11-14]. The lower is viscosity of polymer in molten state the higher filler contents are possible. The highest contents are possible when filler is mixed with low viscosity monomer which is next polymerized “in situ” [15]. Important is also sensitivity of polymer to shear stresses. During mixing of filler with polymer high levels of shear stresses are imposed on molten polymer. This can lead to macromolecules scission and polymer degradation. Also thermal sensitivity of polymer plays significant role. Combining processes are conducted in high temperatures and additionally heat is generated due to energy dissipation.

1.4 Filler properties influence on composite preparation process and composite characteristics

Fillers properties are equally important and sometimes more important for final composites processing and performance characteristics. For example laminates properties are mainly determined by content and type of reinforcing fibres. They are also very important on the stage of composite preparation. Generally is known that filler particles can enhance many performance characteristics.

There are many theories relating viscosity increase with filler content. The oldest and the best known is Albert Einstein’s formula [17] elaborated for rigid buoyant spheres dispersed in Newtonian fluid:

$$\eta_r = \frac{\eta_s}{\eta_0} = 1 + 2.5 \cdot \varphi \quad (2)$$

where: η_r – relative viscosity, η_s – dispersion viscosity, η_0 – pure matrix viscosity.

For filled polymers many different dependences have been proposed [11-13]. The most versatile are formulas in polynomial form [13]:

$$\eta_r = \frac{\eta_s - \eta_0}{\eta_0} = \sum_{n=1} b_n \cdot \varphi^n \quad (3)$$

where b_n coefficients are determined experimentally or are based on theoretical considerations.

In order to properly select filler for given application few factors have to be taken into consideration [1,4,8,11-14,17]. The first significant factor is the nature of filler. Fillers are organic or inorganic in their nature. Wood fillers are of course organic. Organic fillers are more inconvenient during composite blending. First of all organic fillers are highly hydrophilic. Moisture absorbed by filler have to be removed before mixing with polymer to avoid rapid evaporation during processing and composite foaming. In many cases water deteriorates also

polymer properties. The second problem is low thermal resistance of natural materials. Many polymers have to be processed in temperatures above 200°C and high performance polymers even above 380°C. Most of organic fillers and among them wood fillers decompose in temperatures above 200-220°C. But organic nature is also advantageous. Composites filled with organic filler are easier biodegradable than composites with inorganic fillers [8,18,19]. Organic fillers are also cheaper than inorganic. For the environment protection significant is also that most organic fillers originate from renewable resources.

The second important factor for filler selection are fillers physical properties. Many different classes of properties are modified with fillers. To frequently modified belong mechanical, electrical, optical, chemical and biological features. Depending on assumed polymer matrix properties modification fillers with given properties are chosen. For example when electric conductivity is important fillers with good electric conductivity are added (silver plates, graphite, metal powders, carbon nanotubes), when strength properties are important high strength

fibres are applied and so on. Fillers properties are not the only characteristics influencing composites properties so there is not direct proportionality between filler content and extend of given property change.

The third essential factor is geometry of filler. Geometrical parameters influence both performance and processing properties [1,3,11-15,17,20]. Among geometrical features important are mean particle size, particle size distribution, particles aspect ratio, filler specific area and particles shape. It is not possible to discuss all details of this problem so only some aspect will be presented. First of all shape is very important. Fillers may be spherical, platy, rod-like, fibrous and irregular.

Wood particles shape depends strongly on the process of their preparation. Big particles with diameter higher than 1mm are mostly irregular with aspect ratio in the range from 1 to 10. Wood flour (the most popular as polymers filler) have particles with fibrous or rod-like shape [4,8,17,19]. Different shapes of wood particles sieved after milling are shown in Fig. 5. Wood particles with fibrous shape increase strength of many polymers.

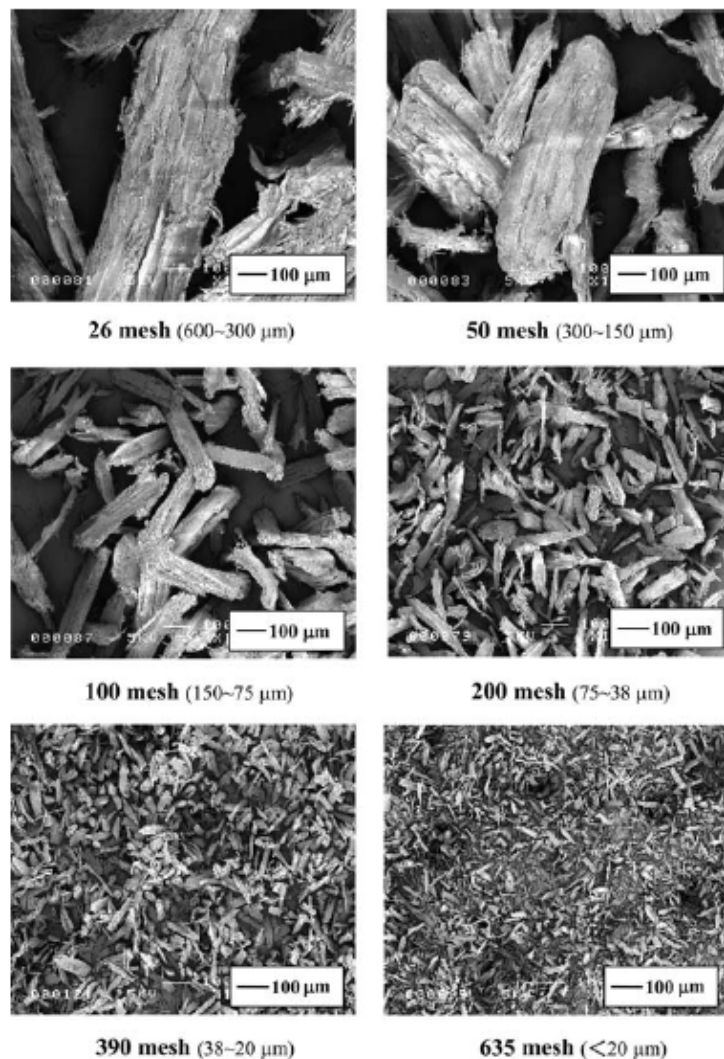


Fig.1. Scanning electron microscope images of wood flour particles separated with sieves of different mesh sizes [20].

Particle size also influence composites properties. The smaller are particles the stronger is effect of particles on many performance features. But simultaneously the smaller are particles the higher are viscosities and more problems appears in composite preparation stage. Very small particles (below 1 μ m) form strong agglomerates and aggregates very difficult to disintegrate during composite combining. The size of applied particles influence also possible processing technologies. Composites with particles bigger than 1-3mm can be processed by compression moulding but can not be processed with thin wall profiles extrusion and injection moulding. Such big particles block processing tools. Injection moulding is possible with very small particles (smaller than 0,1mm) because bigger particles block gates in injection moulds. Taking into account aspect ratio, the higher is this parameter the more pronounced influence on strength properties. Taking into consideration particles size distribution it is observed that the broader is particle size range the lower is viscosity of filled polymer melt and the higher filler concentrations are possible. It is important both for processing characteristics and for filling procedures.

Filler particles geometry influence also elastic properties in molten state manifested by die swell phenomenon [22].

1.5 Interactions between filler particles and polymer matrix

It is not possible to produce high performance composite without good cooperation between polymer matrix and filler particles. In solid state stresses, heat, electricity and other fluxes have to be transported through composites and interface between composite components must not block these fluxes. If there is no bonds between polymer and filler many properties are deteriorated. In this case the only role played by filler is to lower the prize. Such fillers are known as extender. To achieve good cooperation between filler particles and polymer matrix strong adhesive bonds at the interface are needed [1,2,3,14,21]. Good wettability of filler surface with molten polymer is essential.

Theoretically, under equilibrium conditions, low surface energy polymer melts should easily wet the high energy surface, e.g. surface of mineral filler. In reality high energy surfaces attract contaminants and are usually covered with layer of gases and hydrocarbon material adsorbed from atmosphere [11,21]. Additionally and more essentially is that wetting is dynamic process. Experiment and theoretical considerations show that high energy and high viscosity of polymer melts disfavour wetting of filler [11,21].

The first method of this barrier lowering is to coat filler surface with proper surfactant. The second

method is to treat filler surface with chemical agent that changes surface energy of solid particles. The best method is to find chemical agent that is able to chemically bond both with polymer macromolecules and with filler surface. Such chemicals are called coupling agents. Coupling agents not only facilitate filler surface wetting by molten polymer but also form strong adhesion bonds between polymer and filler. This enhances many properties of composites. Coupling agents also facilitate dispersion of filler particles in polymer matrix.

All surface modification methods are applied also for wood fillers [8,10,18,23]. Together with these methods shearing stresses are applied that help to overcome wetting barrier between filler and polymer. It is generally done in filling technologies. Different types of screw mixers are applied, mainly two screws extruders. Screws of these machines are equipped with different mixing and shearing zones to achieve good wetting, composite homogenization and aggregates and agglomerates disintegration [6,23].

1.6 Polymer blends

Utracki [5] defines polymer blend as a mixture of at least two polymers or copolymers with minimum 2% content of each component.

In recycling processes, especially when plastics are collected from municipal solid wastes or industrial wastes, it is very hard to separate all types of polymers. Because of this in many cases one has to do with polymer blends (mixes). Situation is a little bit better when all components are known but in case of municipal solid wastes collection it is rarely met.

As was stated earlier polymer blends can be manufactures from miscible polymers or from immiscible [4,5,23]. These are to extreme cases. In practice miscibility falls between these to extremities. The term miscibility is somewhat controversial and have to be clarified. Most terms relating to mixtures are based on thermodynamics and on analysis of phase diagrams of polymer systems (Fig. 2) [4,5]. A miscible polymer blend is a homogenous polymer mixture at molecular , with negative value of free energy of mixing (Fig. 2a, bottom curve). Immiscible polymer blend exhibit positive value of free energy of mixing (Fig. 2a, upper curve). Blends of two high molecular weight polymers usually gives lower critical solution temperatures (LCST), which means that their mixture may be miscible at lower temperature but phase separate at higher temperature. In the case of opposite character of miscibility blends exhibit upper critical solution temperatures (UCST). The deciding property of true miscibility is mixture thermodynamic stability. The system is thermodynamically stable if its formation is

accompanied by decrease in the Gibbs free energy. When significant interactions take place between components, Gibbs energy difference becomes negative and the blend is miscible. The miscibility is, however, not complete as for small molecules. The complete miscibility is very rare for polymers. An immiscible polymer blend exhibit two or more phases on entire composition and temperature ranges. Partially miscible polymer blends exhibit a “range” of miscibility, they are miscible for certain concentrations and temperatures. In morphological sense miscibility gives single phase over entire concentration at particular temperature.

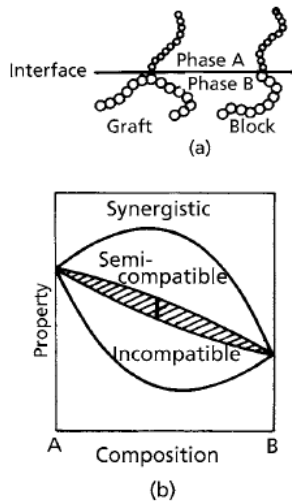


Fig.2. (a) Compatibilisation of immiscible blend of polymer A and B by block or graft copolymers (b) the subsequent modification of property responses [4].

To improve performance characteristics, immiscible blends have to be compatibilized. Compatibilisation is a physical or chemical modification of interfacial properties of an immiscible polymer blend, resulting in formation of interphase and stabilisation of the desired morphology thus leading to polymer alloy creation [4]. Compatibilisation do not lead to miscibility in thermodynamic sense. Due to compatibilisation acceptable properties can be achieved from immiscible polymers. A compatibiliser can either be added to the mixture or generated ‘in situ’ during reactive compatibilisation. It can be a grafted copolymer or, in most cases, block copolymer (Fig. 11). The compatibiliser have to migrate to the interface, reduce interfacial tension, disperse minor component and increase adhesion of phases in solid state. The second function of compatibiliser is stabilisation of blend morphology. There are many, many types of compatibilisers. Each case have to be considered individually. In the literature it is possible to find compatibilisers for many of pairs of different polymers [4,5]. It is also possible to prepare blends of more than two polymers but compatibilisation for such system is much more complicated.

Polymers blends preparation is in some extent similar to filling process. The main difference consists in filler preparation and compatibilisation procedures. As during filling processes in polymer mixtures preparation shearing stresses are applied to achieve mutual polymers dispersion and mixture homogenization. Also for blends manufacture screw extruders are mainly applied.

2. Procedure of samples preparation

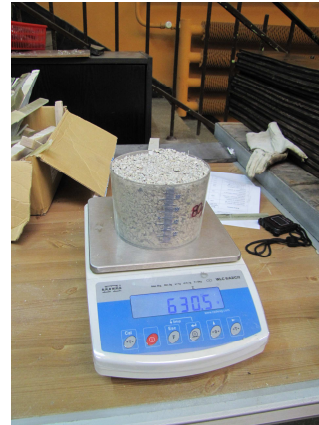


Fig.3. Measurement of bulk density (ABS and wooden made waste Figure description.



Fig.4. Filling the gravimetric feeders.

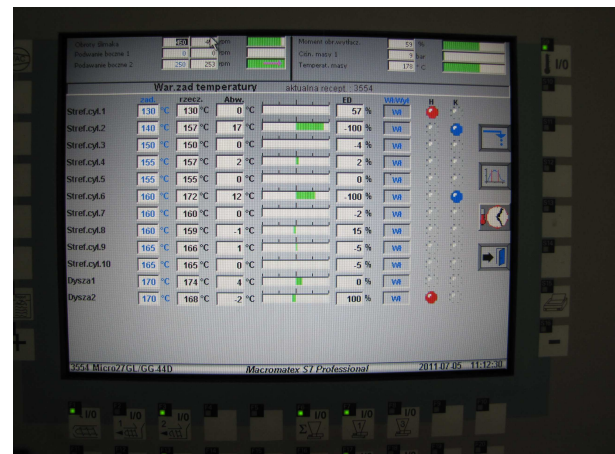


Fig.5. Setting process parametres.



Fig.6. Start the extrusion process.



Fig.7. Composite granulation.



Fig.8. Setting the parameters of injection molding machines used to prepare samples for testing the mechanical parameters of the composite.

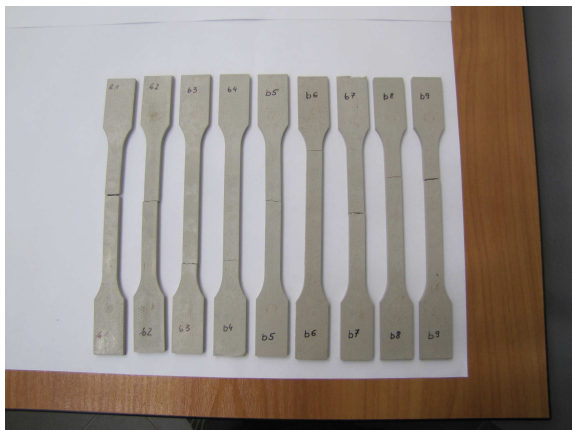


Fig.9.Prepared samples after static extension test.

3. Examining static stretching composites

Investigation of composites is done according to European norm ISO 527, the norm describes general role of designation of reliability properties done in specific environment i.e.g. static extension test.

The norm describes different types of test forms and measurement routines and methods.

Predicted tests are done according to method dedicated for thermoset composites and thermoplastic composites with one dimensional or multidimensional strengthen by batt, different types of fabric, hybrid strengthen and other materials.

Measurement stand are measurement stand for static and dynamic tests, which correspond with requirements described in ISO 5893 norm.



Fig.10. MTS 835 Table Top System.

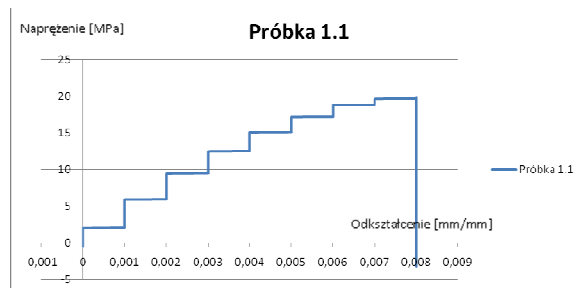


Fig.11. Graph of the dependence of the stress on deforming the 1.1 sample.

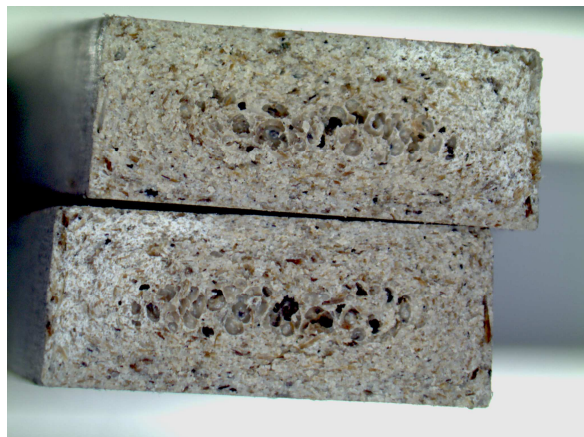


Fig.12. Photograph depicting the 1.2 surface of the sample after breaking.

Conclusions:

Depending on setting and arranging grains of wood in mounting part fittings (samples), as a result of fixing the machine in air handles, appearing of different preliminary power was noticed. The turnout of this power is negative what he determines, that the sample exerted pressure on the sensor of power, caused by her deformation.

Based on surface photographs in the place of breaking individual samples and strength findings it is possible to state, that:

- along with the rise in the content of wood, a hardness and a brittleness of material grow,
- mean of the Young's module in case of marked samples:

- * 1. n takes out - 4446.843 MPa (after rejecting results of outermost- 1.6 samples and 1.9),

- * 2. n takes out - 6248.71 MPa (after rejecting results of outermost 2.1 samples and 2.5),

- * 3. n takes out - 3787.947 MPa (after rejecting results of outermost 3.1 samples and 3.4),

- * b.n takes out - 4231.73 MPa (after rejecting of results of outermost b.1 samples both b.6 and b.4 and b.7).

Individual types of samples, described with different percentage composition of wood, a different line of the trend characterizes. For an example described samples No. 1. have n the smallest durability what it is possible to conclude that they contain the greatest volume of blank spaces in their cross sections by (of air bubbles) and fractions of wood which stand for hours beyond the outline of the above diameter. In case of marked samples No. 2. the durability is n much bigger (about 400 N) towards samples No. 1.n.

Samples by No. 3. have n the greatest durability and undergo considerable extending dating back even a two times of extending 1.n samples.

Marked samples through b.n in particular save b.3, b.5, b.6, b.7, b.9 oneself artistically what one can see on the graph fig. 108. Extending them towards samples 1. n, 2. n, 3. n reaches the row even up to the 300% at the slight increase of power.

4. Charpy impact tests

Very often changeable dynamic loads which are characterized very much by swings turn up at structural members. We say then that we deal with the impact resistance. This phenomenon requires determining separate properties of the material. For determining these properties an impact attempt being aimed at an expression serves the quality of material under the influence of the increased speed loads.

The percussion following tests are applicable: test of stretching out, hugging, turning and bending.

In practice most oftentimes a test of bending carried out on samples with the notch or without the notch is applied. Findings to a considerable degree depend on technological processes, of possible structural defects (especially on the border warp/reinforcement), directionalities of needling, as well as temperatures of examinations. Also a participation of needling in the total volume of composite outweighs. Values of the impact resistance get on samples of the equal kind of the shape aren't comparable with oneself.



Fig.13. Charpy Hammer long with the instrumentation.

Indicating the method: ISO_179-1/e/1.n

Measured impact resistance = 0.0259 acU [kJ/m 2]

Conclusions:

Based on conducted attempts Charpy impact tests they stated, that:

- along with the rise in the content of wood in plastic composites their impact resistance increases, that is a value of the energy which is needed for breaking the sample, grows

- damaging the sample has character of fragile scrap, that is the sample breaks not demonstrating the plastic strain.

5. Summary

Technology of Wood-Plastics Composites (WPC) obtaining from the recycled materials is one of the, most developed modern technologies in the USA, in Poland practically unknown or recognised in very much reduced range. Materials of the type WPC are unusually difficult in the processing what results from wood behaviour in high temperature. In the course of the first alpha tests we managed to establish that the temperature in the homogenisation system cannot exceed the 180 °C, above this temperature thermal decomposition of the wood flour takes place. For processing of polymer-wood mixtures it is possible to apply standard machines for thermoplastic polymers processing. For that purpose single screw extruders are applied and in the recent years double screw extruders with special screw

design are used. In case of the proposed WPC production technology it was assumed that materials applied in manufacturing processes would come from the recycling what creates further complications and challenges consisting in the proper selection of components of the machine for the WPC production. In order to achieve this result one should elaborate the complete know-how, containing the entire production process, in it appropriate its consecutive phases: drying of the wood flour, transport of raw materials, feeding , mixing up, extrusion.

Measured parameters of prepared samples confirm the possibility of using recycled materials to produce fully functional new composite material.

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