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TITLE:
The Effect of Construction and Demolition Waste Plastic Fractions on Wood-Polymer Composite Properties

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KEYWORDS:
Circular economy, construction and demolition waste (CDW), plastic, separation, sorting, recycling, utilization, wood-polymer composite (WPC), mechanical properties

SUMMARY:
Secondary material streams have been shown to include potential raw materials for production. Presented here is a protocol in which CDW-plastic waste as a raw material is identified, followed by various processing steps (agglomeration, extrusion). As a result, a composite material was produced, and mechanical properties were analyzed.

ABSTRACT:
Construction and demolition waste (CDW), including valuable materials such as plastics, have a remarkable influence on the waste sector. In order for plastic materials to be re-utilized, they must be identified and separated according to their polymer composition. In this study, the identification of these materials was performed using near-infrared spectroscopy (NIR), which identified material based on their physical-chemical properties. Advantages of the NIR method are a low environmental impact and rapid measurement (within a few seconds) in the spectral range of 1600-2400 nm without special sample preparation. Limitations include its inability to analyze dark materials. The identified polymers were utilized as a component for wood-polymer composite (WPC) that consists of a polymer matrix, low cost fillers, and additives. The components were first compounded with an agglomeration apparatus, followed by production by extrusion. In the agglomeration process, the aim was to compound all materials to produce uniformly distributed and granulated materials as pellets. During the agglomeration process, the polymer (matrix) was melted and fillers and other additives were then mixed into the melted polymer, being ready for the extrusion process. In the extrusion method, heat and shear forces were applied to a material within the barrel of a conical counter-rotating twin-screw type extruder, which reduces the risk of burning the materials and lower shear mixing. The heated

and sheared mixture was then conveyed through a die to give the product the desired shape. The above-described protocol proved the potential for re-utilization of CDW materials. Functional properties must be verified according to the standardized tests, such as flexural, tensile, and impact strength tests for the material.

INTRODUCTION:

Global waste generation has grown significantly throughout history and is predicted to increase by tens of percentages in the future unless action is taken[1]. In particular, high-income countries have generated more than one-third of the world's waste although they account for only 16% of the global population[1]. The construction sector is a significant producer of this waste due to rapid urbanization and population growth. According to estimates, approximately one-third of global solid waste is formed by construction and demolition projects; however, exact values from different areas are missing[2]. In the European Union (EU), the amount of construction and demolition waste (CDW) is approximately 25%–30% of total waste generation[3], and includes valuable and significant secondary raw materials, like plastic. Without organized collection and management, plastic may contaminate and adversely influence ecosystems. In 2016, 242 million tons of plastic waste were generated in the world[1]. The share of plastic recycled in Europe was only 31.1%[4].

Resource scarcity has created a need to change practices toward a circular economy, in which the aims are to use waste as a source of secondary resources and recover waste for reuse. Economic growth and minimized environmental impacts will be created by the circular economy, which is a popular concept in Europe. The European Commission adopted a European Union Action Plan for a circular economy, which set goals and indicators for contributions[5].

Tighter environmental regulations and laws are contributing to the construction sector putting more effort into waste management and material recycling issues. For example, the European Union (EU) has set targets for material recovery. From the year 2020 onwards, the material recovery rate of non-hazardous CDW should be 70%[6]. The composition of CDW may vary widely across geographical locations but some common characteristics can be identified, including, for example, plastic that is a potential and valuable raw material for wood-polymer composites. The reutilization of plastic is a concrete step towards a circular economy in which virgin plastic polymers are substituted by recycled polymer.

Composite materials are a multi-phase system, consisting of a matrix material and reinforcing phase. Wood-polymer composite (WPC) typically contains polymers as the matrix, wood materials as reinforcement, and additives for improving adhesion, such as coupling agents and lubricants. WPC can be known as an environmentally friendly material because the raw material can be sourced from renewable materials, such as polylactic acid (PLA) and wood. According to the latest innovation[7], the additives of WPC can be based on renewable sources. Additionally, the source of the raw material can be recycled (non-virgin) materials, which is an ecologically and technically superior alternative[8]. For example, researchers have studied extruded WPC that contains CDW, and found that the properties of CDW–based composites were at an acceptable level[9]. Utilization of recycled raw materials as a component for WPC is also acceptable from the environmental aspect, as proved by several assessments. Overall, it has been demonstrated that utilizing CDW in WPC production can decrease the environmental influences of CDW management[10]. In addition, it has been found that using recycled polypropylene (PP) plastic in WPC has the potential to reduce global warming[11].

The amount of available recycled polymers will increase in the future. Global plastic production has increased approximately 9% as per year, on average, and it is expected that this increment will continue in the future[12]. The most general plastic polymer types are, inter alia, polypropylene (PP) and polyethylene (PE). The shares of total demand for PE and PP were 29.8% and 19.3%, respectively, in Europe in 2017[4]. The global plastic recycling market is expected to grow at an annual growth rate of 5.6% during the period 2018–2026[13]. One of the main applications in which plastics is used is building and construction. For example, almost 20% of the total demand for European plastic was associated with building and construction applications[4]. From an economic perspective, the use of recycled polymers in WPC manufacturing is an interesting alternative, leading to the production of materials with low cost. Previous research has shown that physical effects have a stronger influence on extruded materials made from secondary plastic compared to the corresponding virgin material, but properties depend on the plastic source[14]. However, the use of recycled plastic decreases the strength of WPC due to lower compatibility[15]. Variation between the structures of plastic polymers causes concerns for re-use and recycling, which contribute to the importance of plastic sorting based on the polymer.

This study intends to assess the utilization of plastic material from CDW as a raw material for WPC. The polymer fractions assessed in the study are acrylonitrile butadiene styrene (ABS), polypropylene (PP), and polyethylene (PE). These are known as universal plastic fractions within CDW. The polymer fractions are treated with general manufacturing processes, such as agglomeration and extrusion, and are tested with universal mechanical property tests. The primary objective of the study is to discover how the properties of WPC would alter if recycled polymers were used as a raw material in matrix instead of primary virgin polymers.

Based on the (local) waste management center (Etelä-Karjalan Jätehuolto Oy), it was shown how plastic-rich CDW is stored. It was demonstrated that a great amount plastic material is included and some examples of CDW plastic polymers were shown. Researchers collected the most suitable polymers for further processing, such as ABS, PP, and PE. The desired polymers (PE, PP, ABS) were identified using portable near infrared (NIR) spectroscopy. WPC product examples were presented in which where collected plastic materials could be utilized as a raw material. The definition of the composite and its advantages were explained.

PROTOCOL:

1. Identification and pre-treatment

1.1. Identify polymers in plastic with the portable near-infrared (NIR) spectroscopy tool in the spectral range of 1600–2400 nm. Contact the polymer with spectroscopy tool and determine the polymer by the measured reflectance.

1.1.1. According to the identification curve of spectroscopy, analyze the identification results from the screen in the laboratory.

1.2. Based on the identification result, sort materials between the polymers and measure their respective weights.

NOTE: The material was sorted and weighted according to the measured identification results. Selected polymers for further processing were ABS, PE, and PP with the amounts, 27.1, 14.2, and 44.7 kg, respectively.

1.3. Perform size reduction for the selected plastic materials in laboratory conditions with a crusher apparatus. Place collected and identified materials into the apparatus that crushed materials with the mechanical force of hammer impacts.

1.3.1. Crush plastic materials using a single-shaft shredding system with a crusher/shredder apparatus equipped with a sieve size varying from 10 to 20 mm.

1.3.2. Subject the plastic fragments to a low-speed crusher, equipped with a 5 mm sieve. Ensure that the material is homogenous.

1.4. Measure the material amounts for composites. Show a recipe as an example and present these materials in the relative amounts of plastic, wood, coupling agent, and lubricant (64, 30, 3, and 3 wt%, respectively).

NOTE: Three different composites were studied in this study. The recycled plastic polymers from the CDW were ABS, PP, and PE. The filler of the composite material was wood flour, which was prepared from a dried spruce species (*Picea abies*) size reduced using crushing equipment and sieved for a homogeneous size (20 mm mesh). Commercial additives of coupling agent and lubricant were used. The compositions and name of the prepared materials are shown in **Table 1**.

{Place Table 1 here}

2. Processing of WPC materials with extrusion technology after size reduction treatment

2.1. Transfer the identified and pre-treated materials into closer the next (agglomeration) processing step.

CAUTION: The plastic material of ABS includes a styrene component. The International Agency for Research on Cancer considers that styrene is “possibly carcinogenic to humans”. Therefore, the agglomeration step in action was not included in the filming but its process is outlined in this work. Additionally, only PP or PE polymer was used in the extrusion production during filming.

2.2. Perform agglomeration of the material.

2.2.1. Mix all components of the process (polymer, wood, coupling agent, and lubricant) in an apparatus that consists of a turbomixer and a cooler. Agglomerate the materials in the turbomixer until the temperature of the materials reached 200 °C. Due to the combined effect of temperature and friction, the granules materials were formed after the treatment process of agglomeration.

2.2.2. Cool the materials after turbomixer treatment for 4-7 minutes in a cooler apparatus.

2.3. Evacuate material from the process and collect up agglomerated material.

2.4. Transfer the agglomeration–treated materials to the next process step (extrusion).

2.4.1. Click the control panel of the extrusion machine and check for the correct parameters. The average barrel and tool temperatures varied between 167 and 181 °C, and 183 and 207 °C, respectively. The melt temperature varied between 164 and 177 °C, and the die pressures were between 3.7 and 5.9 MPa. Adjust parameters because recycled materials are heterogeneous, and the process requires professional control.

2.4.2. Compound the components using a conical counter-rotating twin-screw extruder with 15 kg/h material output. The parameters of the materials are presented in **Table 2**. After the extrusion process, the profile material of the composite was generated.

{Place Table 2 here}

3. Sampling of produced materials and analyzes of properties

3.1. Prepare samples for mechanical property tests in the laboratory.

3.1.1. Cut samples from extruded profiles with a machine (i.e., a sliding table saw). Three different size specimens are needed for tests: flexural, tensile, and impact strength.

3.1.2. Determine the size of test samples according to the applicable standards, based on the recommendation of EN 15534[16]. According to the standard, test a minimum of five specimens but the number of measurements may be more than five if greater precision of the mean value is required.

3.2. Saw test samples from the extruded materials for the flexural property test, according to the standard EN 310[17].

3.2.1. Use a sliding table saw with the following dimensions for the sample: 800 mm x 50 mm x 20 mm (length, width, thickness).

3.2.2. Manufacture 20 samples for the analysis of flexural properties (strength and modulus).

3.3. Saw test samples from the extruded materials for the tensile property test, according to the standard EN ISO 527‑2[18]. Use the sliding table saw to cut the material into the following dimensions: 150 mm x 20 mm x 4 mm (length, width, thickness).

3.3.1. Set the material preforms for machining of a dumb-bell shape via computer numerical control (CNC). The width of the sample at its narrow portion was 10 mm, and the cross-sectional surface area of the sample was 4 mm x 10 mm, where the tensile stress was addressed. The length of the narrow portion was 60 mm, ending in a rounded corner with a radius of 60 mm.

3.3.2. Make 20 samples for the analysis of tensile properties (strength and modulus).

3.4. Saw test samples from the extruded materials for the impact strength test, according to the standard EN ISO 179-1[19].

3.4.1. Use the sliding table saw to cut the samples into the following dimensions: 80 mm x 10 mm x 4 mm (length, width, thickness). Make 20 samples for the analysis of impact strength property.

3.5. Move the test material into the 23 °C and 50% relative humidity condition chamber, according to standard EN ISO 291[20], until a constant mass is reached. Ensure that samples are conditioned before the testing of material properties.

3.6. Perform the tests (flexural, tensile, and impact). Determine the mechanical features of specimens by flexural and tensile strength tests with a testing machine in accordance with the EN 310[17] and EN ISO 527-2[18] standards, respectively.

3.6.1.1. Perform flexural strength and modulus test for each of 20 samples, using the testing apparatus. Set flexural test sample at the support of two points and apply a load to the center of sample by clicking **Test start** in the computer program that controls the testing apparatus, with a pre-load of 15 N and test speed of 10 mm/min. The test stops automatically after recording the result. Remove test sample from the support tools and set a new sample on the tools.

3.6.1.2. Repeat procedure until 20 samples were tested and results from the program were registered. The computer program calculates average results from the test.

NOTE: The protocol can be paused here while test tools will be changed for the testing apparatus.

3.6.2. Perform tensile strength and modulus test for 20 machined (dumb-bell-shaped) samples. Set the tensile test sample between the test tools and attach pneumatic clamps, which will keep the sample in the tools during the test. Start the test from the computer control panel, with a pre-load of 10 N and test speed of 2 mm/min, and attach an extension meter tool immediately after the test start.

NOTE: The extension meter tool measures the tensile modulus from the sample. Each test stopped automatically after its result was recorded.

3.6.2.1. Remove the test sample from the tool after each test and set a new sample on the tools. Repeat procedure for all samples. The computer program calculates average result values.

3.6.3. Perform an impact strength test with an impact tester, according to standard EN ISO 179-1[19]. Set the 10 mm x 4 mm size of (width, thickness) sample between the support, reset the force and release the impact hammer of 5 kpcm.

NOTE: The impact strength test sample ruptures due to the impact of hammer and the amount of absorbed energy is visible in the tester indicator.

3.6.3.1. Record the result and repeat the for the 20 samples, after which the average value of impact strength is calculated. The recorded results were in "kpcm" unit, which was changed into joule (J), and the results were presented as a kilojoule per square meter.

NOTE: The span between sample support (distance between the lines of the contact the of sample) in the impact strength test was 62 mm or, alternatively, 20x its thickness.

3.7. Analyze the results from the mechanical tests, which are presented in **Figures 1-3**.

REPRESENTATIVE RESULTS:

To investigate the effect of CDW plastic polymer on the mechanical properties of WPC, three different polymer types as a matrix were studied. **Table 1** presents the composition of materials and **Table 2** reports the manufacturing processes. The material of CDW-PP requires a higher treatment temperature for tools but, correspondingly, melt pressure was lower compared to the other materials (CDW-ABS and CDW-PE).

Figure 1 presents the flexural strength of material (an average from 20 measurements) as bar charts, including standard deviations as an error bar. The highest flexural strength values were achieved with material containing a recycled ABS polymer in a matrix. Almost congruent high-strength quality was achieved in the material in which recycled PE polymer was used in a matrix. The lowest flexural strengths were achieved with material containing a recycled PP polymer in a matrix. **Figure 1** also presents similar results for the flexural modulus of materials, which was measured simultaneously with the strength property. However, even though recycled ABS and PE polymers have congruent results as in the strength tests, the flexural modulus results were different. The recycled PE materials have a significantly lower modulus value compared to the value of recycled ABS polymer.

{Place Figure 1 here}

Figure 2 shows the tensile strength and modulus (an average from 20 measurements) as bar charts, including standard deviations as an error bar. The materials, in which recycled ABS and PE were used, have almost congruent tensile strength results but the standard deviation was higher for the material in which recycled ABS was used. The weakest tensile strength was achieved material containing a recycled PP polymer in a matrix. The results of tensile modulus were congruent with the results of flexural modulus, in which the best modulus was achieved with the recycled ABS polymer.

{Place Figure 2 here}

Figure 3 displays the impact strength properties of materials (an average from 20 measurements) as bar charts, including standard deviations as an error bar. The impact strengths of recycled ABS and PP polymers were almost at the same level, but greater impact strength was achieved with the recycled PE polymer, which had the best impact strength property in this study.

{Place Figure 3 here}

ABS polymer consists of three monomers, which might increase the favorable behavior within the WPC. For example, the acrylonitrile component contributes strength, butadiene components contribute impact resistance, and styrene components contributes rigidity. PE-based WPC accounts for the largest market share, for examples in North America, and it is easy to nail, screw, and saw. However, PE is manufactured in various polymeric forms, such as high-density polyethylene (HDPE) and low-density polyethylene (LDPE), which have different features. The PP-based WPC had the weakest properties in this study, consistent with the fact that its market share is relatively small. Although it has several superior properties compared to polyethylene, such as being lighter and stronger, it is also more brittle than polyethylene[21].

Overall, recycling of composites is the ecologically preferable pathway[8], and recycled waste plastic is a suitable raw material for composites, in which performance can be improved using compatibilizers[22]. The reason for varied mechanical properties might be due to the composition of materials and, in particular, the coupling agent may have a significant effect. The mechanical properties of recycled polymers in WPC were improved with compatibilizers but the effects depend strongly on the agent used and its amount in the structure, causing a large variation between the used agents[23]. A previous study indicated that the highest performance of PP based WPC was achieved with amounts of compatibilizers at three percentage levels[24], which is congruent with the amount used in this study. Thus, the coupling agent used might be more problematic than the level of agent. However, it is generally accepted that the mechanical performance of WPCs is improved when coupling agents are used under optimized conditions[25].

Each polymer has individual features in material, demonstrating that separation of polymers increases the value of WPC with the correct additives. In future, novel eco-friendly alternative coupling agents for recycled polymer composites might be used to meet demand, such as the starch gum shown in a new study of Rocha and Rosa[26]. Additionally, the re-utilization of plastic must make economic sense, and thus also require future action.

FIGURE AND TABLE LEGENDS:

Table 1: The composition of the studied materials. The name of the sample consists of the included matrix component, recycled acrylonitrile butadiene styrene (ABS), polypropylene (PP), and polyethylene (PE) from the construction and demolition waste (CDW). The amounts of wood, coupling agent (CA) and lubricant (Lubr.) were the same in all samples.

Table 2: Processing parameters of the composite materials. (Values after the '±'-mark indicate standard deviations. Avg. = average)

Figure 1: The flexural properties of the studied materials. The flexural strength is presented in the solid color filled bars (red, green, and blue) and the flexural modulus is presented using the same colors in pattern-filled bars. The standard deviations are described as error bars.

Figure 2: The tensile properties of the studied materials. The tensile strength is presented in the solid color filled bars (red, green, and blue) and the tensile modulus is presented using the same colors in pattern-filled bars. The standard deviations are described as error bars.

Figure 3: The impact strength properties of the studied materials. The impact strength is presented in the solid color filled bars and the standard deviations are described as error bars.

DISCUSSION:

The mechanical properties of WPC play an important role in deciding the suitability of these products in various applications. WPC consists of three main ingredients: plastic, wood, and additives. The mechanical properties of fiber-based composites depend on the length of the used fiber, where "critical fiber length" is the term used to indicate sufficient reinforcement[25]. In addition to the properties of ingredients, the quality of raw materials is the important factor for the performance of WPC. In this study, in particular, where recycled raw materials were used, a lot of attention was placed on the raw materials. This study used materials sourced from CDW which can vary between construction sites, and this variability is a critical factor in the comparison of different studies. Therefore, material must be studied according to the standardized tests that ensure uniform product quality.

In a flexural test, the WPC material experiences compressive stress at the load-bearing side and correspondingly, tensile stress at the opposite end. The test method is based on the standard of wood-based panels (EN 310), illustrating the flexural properties of an extruded profile in actual use. The flexural test will cause compression (on the upper surface) and tensile (on the underside) stress for the material, therefore it is important that the extruded (hollow) profile is symmetrical. Another test for flexural property (for example, the standard EN ISO 178[27]), where the dimensions of the sample were smaller, will not yield the real valued for the extrusion profile used but will analyze the property of the material without the effect of a hollow profile. It is important to use a standardized distance between the support spans because this has an influence on the results. The flexural strength depends linearly on the support span, in which an increased support span leads to a proportional decrease of the load[28].

Generally, tensile modulus increases with the increasing content PP polymer within wood fiber[25]. Therefore, we can assume that the composition of materials, including additives such as a coupling agent, were not optimal for this material. The highest variation between the thicknesses of tensile test samples was 0.94 mm; this variation indicates the fastening of samples is a critical step. The testing machine included pneumatic fasteners that cause superfluous force with the various thicknesses of samples. Therefore, the force measurement must be reset at the start of the tensile test in order that the pneumatic fasteners will not distort the results. Alternatively, this troubleshooting could be eliminated by manufacturing homogenous test samples during the sampling phase.

The impact strength test illustrates a different mechanical feature of the material because it measures a momentary strain, while most of the other tests measure the long-term strain of the material. The increasing content of wood fiber decreased the impact strength[25]. The dimensions of the samples must be measured in all tests, and there may be variations between researchers in the use of measuring devices (e.g., compression force in the use of a caliper or micrometer). Therefore, it is important that the same person measures the dimensions of samples in every test, thereby excluding human errors in the measurements. Another option as a modification technique is to use a device that includes a moment for compression. In addition, the test atmosphere may have an influence on the studied properties. In this study, all studied tests were performed under the same conditions, so the effect of atmosphere was similar, and had a coincident effect for every test. As a future application, the tests could be performed in a room where atmosphere is set to be stable.

Because WPC consists of at least two materials, such as wood and polymer, it can complicate the selection of a standard. For example, there may be suitable standards for wood materials, as well as for polymer materials, that will cause limitations in the selection of an appropriate standard for study. The standard organization has published standards (EN 15534-1:2014+A1:2017) in which test methods for composites made from cellulose-based materials and thermoplastics were characterized. The standard allows researchers who follow the European Standard to act in a universal way in their studies. A complication may arise if a significant portion of researchers follows another standard (e.g., ASTM International), which will cause problems in the comparisons of results. A future development may be a single standard organization whose standards would be valid globally.

The standards of WPCs include detailed instructions for the measuring of properties but the interpretation of these may vary between researchers. Benchmarking between research organizations could unify operation methods but may not be allowed because the research organizations are often restricted institutions dealing with confidential information. Therefore, this kind of visually described work ensures test practices are universal for a wider number of people, thereby restricting the possibilities for misunderstanding.

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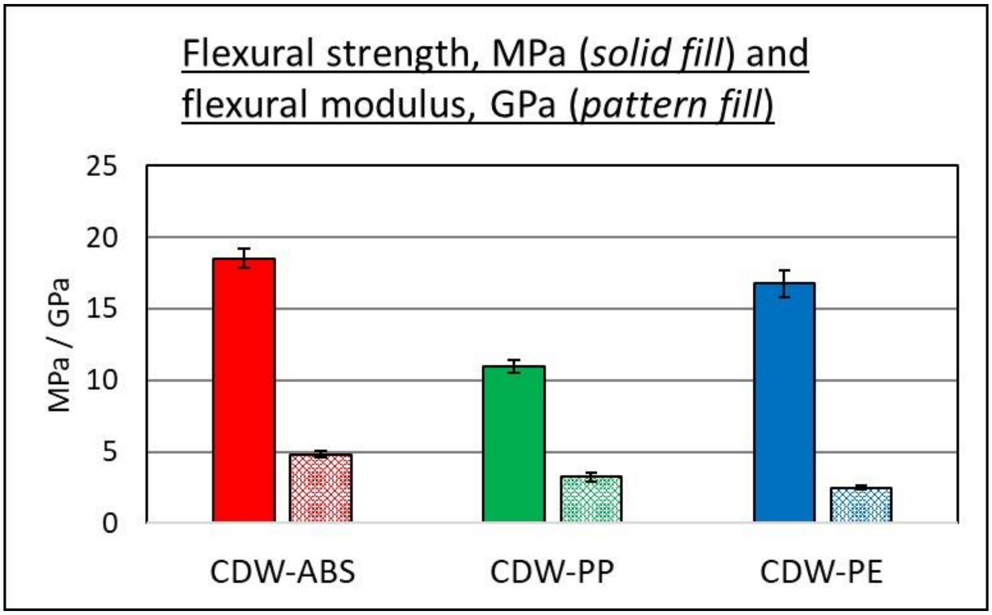
Flexural strength, MPa (*solid fill*) and
flexural modulus, GPa (*pattern fill*)
MPa / GPa
25
20
15
10
5
0
CDW-ABS
CDW-PP
CDW-PE

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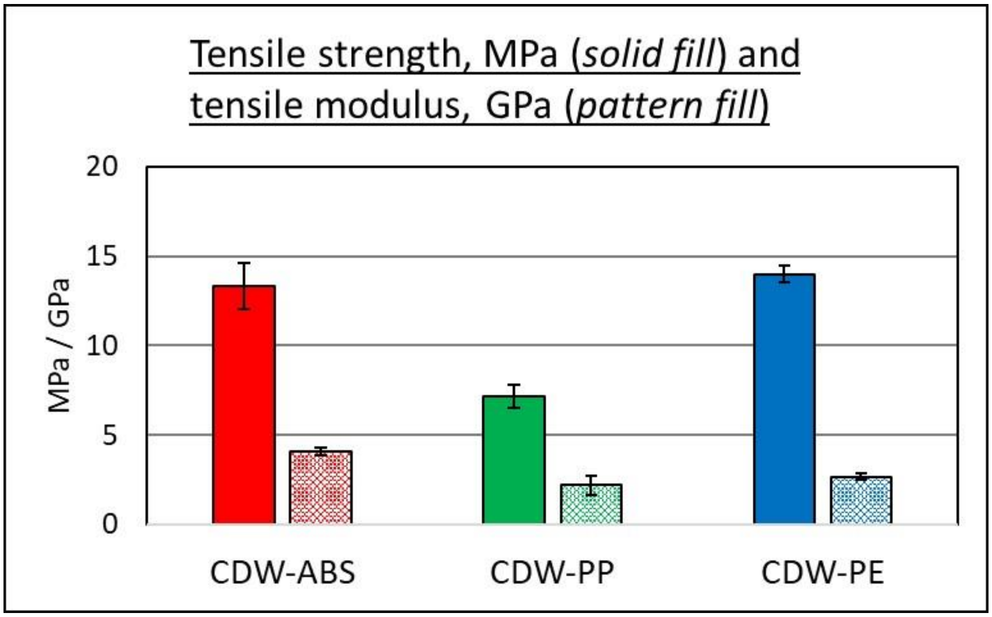

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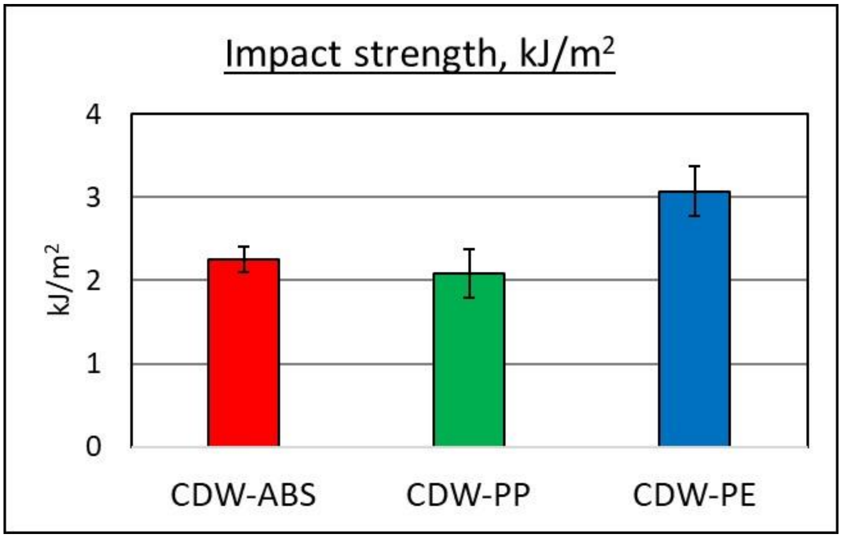

Figure 1 in svg format

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Figure 3 in svg format

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Material	Polymer / amount	Wood	CA	Lubr
CDW-ABS	ABS / 30	64	3	3
CDW-PP	PP / 30	64	3	3
CDW-PE	PE / 30	64	3	3

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Material	Barrel T °C	Tool T °C	Melt T °C	Melt Pressure (bar)	Feeding rate (kg/h)	Avg.Screw speed (rpm)
CDW-ABS	181 ± 11.9	189 ± 14.7	177	50	15	14
CDW-PP	170 ± 10.4	207 ± 8.62	164	37	15	15
CDW-PE	167 ± 8.51	183 ± 10.1	164	59	15	13

Table of Materials

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Name of Material/Equipment	Company	Catalog Number	Comments/Description
Agglomeration	Plasmec	TRL100/FV/W	apparatus of turbomixer
Agglomeration	Plasmec	RFV 200	apparatus of cooler
CNC router	Recontech	F2 - 1325 C	CNC machine
Condition chamber	Memmert	HPP260	constant climate chamber
Coupling agent	DuPont	Fusabond E226	commercial coupling agent additive
Crusher 1 (crusher/shredder)	Untha	Untha LR 630	10-20 mm sieve
Crusher 2 (low-speed crusher)	Shini	Shini SG-1635N-CE	5 mm sieve, granulator
Extruder	Weber	Weber CE 7.2	conical counter-rotating twin-screw
Lubricant	Struktol	TPW 113	commercial lubricant additive
NIR spectroscopy	Thermo Fisher Scientific	Thermo Scientific microPHAZIR PC	
Recycled material ABS from CDW			
Recycled material PE from CDW			
Recycled material PP from CDW			
Sliding table saw	Altendorf	F-90	circular saw/sliding table saw
Testing apparatus	Zwick	5102	impact tester
Testing machine	Zwick Roell	Z020	allround-line materials testing machine
Wood flour (Spruce) material			
WPC example material	UPM Profi		Decking board

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Lappeenranta, April 28, 2020

Editor of Journal of Visualized Experiments, JoVE
Manager of Review, Nam Nguyen

Dear Nam Nguyen

Thank you for your constructive comments about our text, particularly in protocol section. I'm glad to send you our re-revised manuscript, "*The Effect of Construction and Demolition Waste Plastic Fractions on Wood-Polymer Composite Properties*", made by **Ville Lahtela**, **Marko Hyvärinen** and **Timo Kärki**. We considered your comments very carefully, and according to those, we have made changes in the manuscript. The corrections and addendums are highlighted by green colored font. Previously, we have used red (1st revision) purple (2nd revision) and light blue (3rd revision) colored font for corrections and addendums.

The detailed corrections and responses to the comments are listed as follows:

EXAMPLE
- "*Editors/Reviewers' comment*" → Our response.

- *"A general process schematic would help greatly here."* → That is true but after the exhaustive reviewing of protocol section in this version, we believe that the protocol section is enough clear, and a schematic figure is not necessary for the audiences.

- *"How much plastic materials were used?"* → Acknowledged. All of selected plastic materials were used and this was clarified in the text. The material amounts were presented in a previous lines (141-142).

- *"This sounds like scripting language for filming. Please revise the language in the protocol to be geared towards users of the protocol for replication.*
  I have revised steps 1.1-1.3 to fit our publication standard. Please review. This could possibly be deleted."
  → Acknowledged. Revised and reviewed.

- *"What is actually happening here? Where are things being moved to?"* → The prepared materials are ready for next step that is agglomeration. (it might help your filming and editor staff for planning the article).

- *"Cool how and for how long?"* → Acknowledged. Cooling process was explained more accurate.

- *"What are the parameters used for this test? How much of a load and for how long?"* → Acknowledged. Parameters (pre-load and test speed) for flexural strength were added.

- *"What are the parameters used for this test?"* → Acknowledged. Parameters (pre-load and test speed) for tensile test were added.

- *"What are the parameters used for this test? We need more than a citation here so that others can reproduce the protocol. The manuscript should be able to stand alone. What force is applied? At what distance?"* → Acknowledged. Parameters and more information for impact strength were added. Distance is explained in the following lines, 283-284.

- *"This is the type of scripting language that must either be revised or removed."* → Acknowledged. Calculation of impact strength was revised.

- *"This is the type of scripting language that must either be revised or removed."* → Acknowledged. Topic 3.7. (mechanical test results) were revised.

We ask you to kindly consider the manuscript for publication in your journal. As we have previously mentioned, the manuscript is our original work and has not previously been submitted for publication in this journal, before the peer-reviewing process, or elsewhere. We also repeat the need of study again as follows; *The explanation for the need of study as follows: Due to the increased amount of waste generation and reduced amount of resource have been created a need to change global practices toward a circular economy model, where the aim is to use waste as a source of secondary resources and recover waste for reuse. In this research study, recycled plastic fractions from the source of secondary raw material streams, more exactly from the stream of construction and demolition waste, were used as a potential material in the production of wood-polymer composites. Raw materials were identified and separated, followed by a few processing steps of composite manufacturing processes. As a result of the processes, composite materials were produced, and various mechanical properties were analyzed. The manuscript contains essential and viable information for the professionals and researchers focusing on the development of novel composites, which based on the recycled materials from the source stream of construction and demolition waste.*

We hope that this manuscript receives a positive response from you.

Thank you for your considering this paper. We hope that the amendments please you.

Yours faithfully,

Ville Lahtela, the corresponding author