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RubWPC

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Rubber Fusion of Wood Plastic Composite to Make Functional Composites for Building Applications

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1. Abstract

The aim of this report is to present a complete assessment of recycled wood, rubber and thermoplastics at a European level.

After discussions at the second meeting of the RubWPC group it was agreed that this Work Package would concentrate on the types of materials known to be suitable for manufacturing wood / thermoplastic / rubber composites. The assessment was made taking into account only the thermoplastic materials that were thought to be suitable to be used in the RubWPC project.

The compilation of information was done using internet investigations, consultation of European legislative and standard documents and also existing knowledge of the partners involved.

The outcome of this assessment has been an extensive compilation of information regarding the state of the art of process technologies, legislations in place, quality control and sources of the three raw materials to be used in the RubWPC project. Also databases of EU companies capable of supplying the three components of the planned composite were produced, introducing where possible details of the product specification they can supply.

2. Introduction

The internet research and experience of staff at Crumb Rubber Ltd, Ecodeck Ltd and University of Girona (previously Modifibres) was used to identify companies involved in the recycling of polyolefins, PET, producers of wood flour suitable for use in the planned composite and producers of suitable fine rubber powder based on end of life vehicle tyres.

The information was compiled by product group into Excel spreadsheets detailing the company, EU member state, if they belonged to a recognised trade association, their website address and the type of product they produce. For wood flour and rubber where possible the available product size distribution was listed. The European recycling industry is not as sophisticated as the virgin material industries so the detail on products and specification was often limited. The thermoplastics and rubber components for this project are sourced from recycled feedstock. The wood flour component is produced from virgin timber.

3. State of the art of recycled thermoplastics, rubber and wood.

The recycling industry has developed rapidly since the earlier 2000's driven by the oil price rising to over $100 per barrel increasing the feedstock prices for many plastics and rubbers and the pressure on reducing landfill in the EU which has applied considerable pressure to recycle thermoplastics, rubber and wood.

The current "state of the art" is described below for each of the three materials. Attached to this report is the database of potential producers of raw materials to be used on the RubWPC project in an Excel spreadsheet.

3.1 Thermoplastics

From the three main components of the planned composite the thermoplastics recycling industry is the largest, the most diverse and sophisticated in terms of process technologies.

A decision was taken at the second meeting of the partners of RubWPC to focus the research on companies that produce polyolefins and PET as potential feedstocks. This was because nylon, ABS, PS, PVC and PC are known to be unsuitable to use in this project.

Feedstock /Sources of material

Recycled thermoplastics can be obtained by three main supply chains:

- Recycling of end of life industrial waste
- Recycling of in process waste
- Recycling of post consumer waste

The first supply chain produces a good quality recyclate that often allows the polymer to be reused at a controlled percentage back into the same or different product in house.

The second supply chain includes both process waste and rejected components which did not met production standards or specifications required for a determined product. As a result, the "pedigree" of the waste stream is known, as are any contaminants so they can be successfully managed to produce a clean feedstock for the same or other products.

The last category is the largest, the most complex and also the most cross contaminated. Within the post consumer plastic waste that is suitable for recycling, there are a large variety of plastics that have different compositions, colours and properties. This type of waste source is generally grouped in five categories [1].

- Plastic bottles, pots, tubs and trays – that are generated mainly by household waste.
- Plastic film (includes plastic shopping bags, rubbish bags, bubble wrap, and plastic or stretch wrap) - Main source of this films are companies responsible to wholesale and distribution activities.
- Rigid plastics (includes crates, pipes, containers and mouldings) – These plastics can be originated from a variety of sources from industry to agriculture.
- Plastic foams - the most common plastic foam used is expanded polystyrene used in packaging.
- Flexible plastics (includes strapping and cable sheathing).

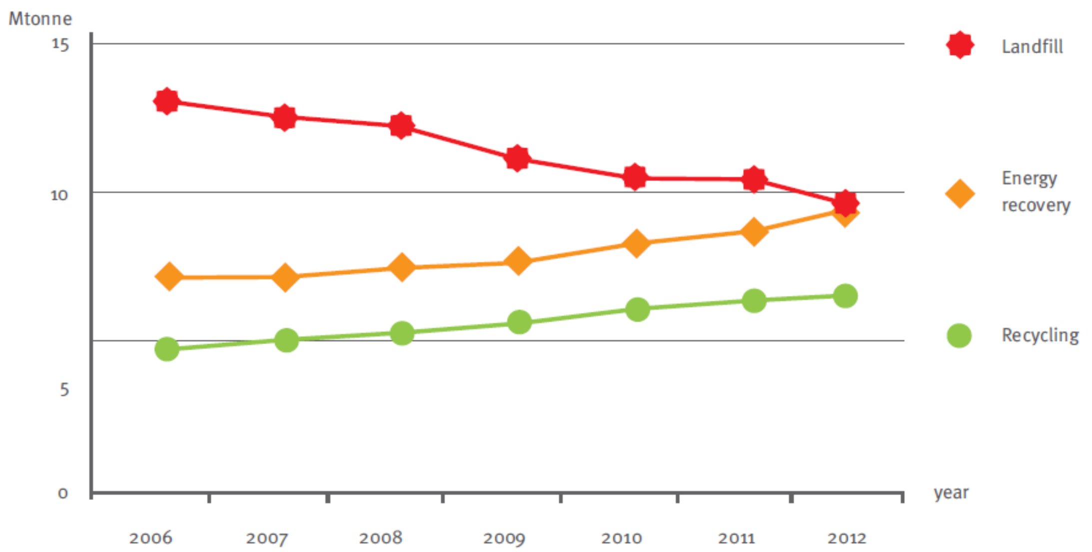

Figure 1 Destination of post consumer plastic waste 2006-2012 [2].

The total amount of post consumer plastic waste generated has been increasing throughout the years in Europe (Figure 1). In 2012, the quantity of post consumer plastic waste generated was 25.2 Mtonne, from which 26.3% was diverted to recycling facilities, corresponding to 6.6Mtonne of waste plastic recycled in that year. Intimately related to this increase is the growth in recovery operations, these increased about 4.7% for the collection of post consumer plastic waste for mechanical recycling.

From all the post consumer plastic waste around 77% was generated by the following European countries: Germany, UK, France, Italy, Spain, Poland, and the Netherlands.

Packaging plastic waste was the dominant waste within this category covering 62.2% of the total generated post consumer plastic waste [2].

Process

The European recycling market is rapidly evolving, in particular with the latest technologies that are able to separate co mingled post consumer scrap into discreet clean/decontaminated polymer streams, making their reuse viable.

Collection

The recycling process starts with the waste collection and determines the composition of the waste stream, influencing all the recovery operations ahead. Nowadays, collection schemes of dry recyclables as household plastic goods and others such as metals, glass, card and paper have been done throughout Europe and it is a valuable solution to maximize the amount of waste that can be recovered into a quality resource instead of going to landfill.

Pre-treatment

The pre-treatment necessary to each waste differs from recycler to recycler but can include plastic separation, washing, de-contamination and sorting. There is a wide range of technologies used in the industries to pre-treat the waste that arrives at the recycling plants. They go from manual sorting and picking to automated processes such as, shredding, sieving, air and liquid density separation processes, magnetic separations and highly sophisticated spectrophotometer sorting technologies such as UV/VIS, NIR and laser techniques.

Some of these recycling units are highly complex and efficient being able to produce around 100,000tonnes/year and obtain purity higher than 95%.

Mechanical Recycling

The mechanical recycling of plastic products consists in different mechanical processes, such as, grinding, separation, drying, re-granulation in order to recover plastic waste into plastic recyclates that can be used in new applications without modifying the polymers molecular structure.

The ideal input for mechanical recycling are streams of homogeneous thermoplastic type materials (because they can be re-melted and re-processed) that are clean and preferably free of contaminates.

The output from the process is either flakes or granulates. Depending on the efficiency of the pre-treatment and recycling process these flakes/granulates may still have contaminants in it such as ink, metal, non plastic material or other polymers. In some cases, recyclers have another stage on the recycling process that includes an extrusion process to further clean the material. The extruder is equipped with a melt filter which helps to remove many of the contaminants present on the material. When the material is subjected to an extrusion usually the final product obtained is a granule/ pellet which are physically similar to the virgin material [3].

Feedstock Recycling

Feedstock recycling is a valuable option when low quality mixed plastics, plastics contaminated with food or composite plastics are involved because these are very difficult to recycle by the mechanical recycling process. These type of materials are not suitable to recycling but can be used in gasification or pyrolysis processes.

Legislation

Currently the European directives in term related to the regulation of recycling processes of plastic wastes are the Waste Framework Directive 2008/98/EC and the Packaging Directive 94/62/EC. The Packaging directive is applicable in recycling of post consumer plastic waste because most of this waste comes from packaging products.

Waste Framework Directive – 2008/98/EC

This directive establishes the legislative framework for the handling of waste, providing clarification on basic waste management principles and definitions such as, waste, by-product, recycling and recovery. The directive also presents the necessary requirements for an establishment to carry out waste management operations taking in to account human health and the environment.

Two new recycling and recovery targets are established, a minimum recycling target of 50% for household waste and 70% for building and construction waste to be achieved by 2020 by all EU Member States [4].

Packaging Directive – 94/62/EC

This Directive aims to standardize processes in order to prevent or reduce the impact of packaging and packaging waste on the environment and to ensure the well functioning of the Internal Market. It contains provisions on the prevention of packaging waste, on the re-use of packaging and on the recovery and recycling of packaging waste.

In 2004, the Directive was reviewed to provide clarification on some terms and definitions and also new recovery and recycling targets of packaging waste were imposed. In 2005, the Directive was revised again to allow new Member States to reach the recovery and recycling targets presented on the directive [5].

Quality /Specifications

Throughout the world the quality control of recycled plastics varies greatly. In some cases recycling industries don't follow any specific standards and generally the recycled material has low specification. In these cases the quality of the recycled material is usually linked to the quality of the feedstock and to the effectiveness of the recycling process.

Whilst there are exceptions, e.g. HDPE and PET from post consumer waste being recycled into bottles the specification of recycled plastic usually only covers melt flow index (MFI) and density.

One of the problems when dealing with plastic recycling is the identification of the material being treated. In order to facilitate the recycling process some institutions/associations in different countries recommend the use of a coding system to indentify larger plastic parts and plastic packaging.

For plastic packaging products, many countries are adopting the identification code developed by the American Society of the Plastics Industry – SPI (Figure 2). There is currently no mandatory need to identify the different plastics produced but it is considered of good practise to use an international recognised recycling code [6].

Figure 2 Polymer identification code from SPI [7].

When is not possible to identify the plastic by their codes, it is common in the industry to realise some simple and easy tests in order to have an idea of the material being recycled. Some of these tests are straightforward and there is no need of any special equipment. An example of these are the float test where some of the waste is put in water and oil in order to distinguish materials by their characteristic densities. The flame test is another commonly used test to distinguish different plastics. When the plastic enters in contact with the flame it can present different colours depending on the type of plastic being tested. Also by bending the sample it can be known if the plastic is rigid or flexible [1].

For some of the industries, quality control can be as simple as a visual inspection and matching some of the materials characteristics with a list of non acceptable features or by performing the simples tests described above. Others can have a better defined quality control system where detailed laboratory tests are included in order to have a more accurate composition of the waste being treated.

Other measures of quality control that can be used are related to the handling and storage of the waste materials. They should be handled and stored in a way that the plastics are protected from moisture, dirt and sunlight.

Within the challenges of plastic recycling quality control of plastic waste is regularly one of the topics arising. The big challenges for the recycling of this type of waste are the elimination of contamination and also the high variability of the recycled batches of recycled material that greatly contributes to the quality of the recyclate.

For this reason, quality control implementation in the recycling industry is of extreme importance to minimize contamination and generate more consistent batches of recycled materials.

Recently in order to standardize post consumer plastic waste recycling and try to obtain a more consistent and good quality recyclate among the plastic industries, the European Commission co-funded a project, EuCertPlast, which aimed the creation of a certification for post cycle recyclers.

The certification works according the European standards EN 15343:2007 for assessment of conformity and recycled content as well as traceability. Its objective is to encourage plastic recyclers to work according to the standards presented in Table 1 in an environmentally friendly way. This certification also brings standardization for the characterisation of specific recycled outputs [8].

Table 1 – European Standards for plastic recycled outputs [8].

Document Number	Title
EN 15343:2007	Plastics - Recycled Plastics - Plastics recycling traceability and assessment of conformity and recycled content.
EN 15347:2007	Plastics – Recycled Plastics – Characterisation of plastics wastes.
EN 15342:2007	Plastics – Recycled Plastics – Characterisation of polystyrene (PS) recyclates.
EN 15344:2007	Plastics – Recycled Plastics – Characterisation of Polyethylene (PE) recyclates.
EN 15345:2007	Plastics – Recycled Plastics – Characterisation of Polypropylene (PP) recyclates.
EN 15346:2007	Plastics – Recycled Plastics – Characterisation of poly(vinyl chloride) (PVC) recyclates.
EN 15348:2007	Plastics – Recycled Plastics – Characterisation of poly(ethylene terephthalate) (PET) recyclates.
CEN/TR 15353	Plastics – Recycled Plastics – Guidelines for the development of standards for recycled plastics.
EN ISO 472:2001	Plastics, vocabulary.

In terms of quality control, all the recyclers that want to be certified by EUCertPlast have to a have a strict quality control system. For each type of polymer the standards have a defined tolerance for the required and optional characteristics of a specific recyclate.

For example for required assessment of quality of PP recyclates following EuCertPlast, recyclates have to be visual inspected to analyse colour and shape. It is also required an analysis of density, melt flow rate and impact strength test. As optional, parameters like the ash content, bulk density, extraneous polymers, flexural properties, filtration level, recycled content, tensile stress at yield, tensile strain at break and volatile content can be tested [9].

The specifications and the standard deviations to the values obtained in each specification shall then be agreed between the supplier and the purchaser.

The recyclers should have also a quality management system certified to EN ISO 9001 in order to guarantee a consistent recyclate quality.

A number of trade organisations have evolved within the plastic recycling industry, some are national organisations, and others are pan European e.g. European Association of Plastic Recycling (EPRO) [10].

3.2 Rubber

The successful recycling of end of life vehicle tyres (EOLVT) is a global challenge. There are currently stock piles of tyres around the world. The EU has banned the landfill of EOLVT but there is insufficient demand /applications for reprocessed rubber within the EU and therefore there are exports to certain other regions of either whole tyre or downsized material, often as tyre derived fuel (TDF) to be used in power stations to produce electricity.

Feedstock /Sources of material

The rubber that is intended to be used in the RubWPC project is recycled rubber powder from end of life vehicle tyres.

Tyres are highly complex items consisting of steel, fabrics (made from nylon or polyester) and up to 16 different rubber compounds. The compounds are designed to meet the technical requirements of different parts of the tyre (such as the bead, side wall and tread compounds) and also different performance requirements that different vehicles have. Due to this the formulations of tyres are highly complex. Their components include natural rubber (NR) synthetic rubbers (SBR), carbon black, process oils, silica, sulphur and other additives. Further complexity occurs because each tyre manufacturer has their own proprietary formulations.

The feedstock for the tyre recycling industry includes tyres from passenger cars, trucks, large machines (e.g. tractors and earth movers) and aircraft. Within all of these categories the largest volumes are from car and truck tyres. Similar to the feedstock for thermoplastic recycling the feedstock for rubber recycling can have great variability.

Process

The tyre recycling process is generally "low technology" and basically consists of a multi step size reduction of the tyre. The majority of tyre recyclers take whole tyres and put them through a mechanical shredding, rasping and granulation process to downsize the material. The segregation of car and truck tyre is not common and there is no segregation by manufacturer.

The most common output from this process is a product in the 20mm to 3mm size range. All tyre recyclers will have some stage where a percentage of the metals, fibres and stones are removed. Like any grinding process a fine fraction, i.e. sub 1mm is produced but this is viewed as a by product by the recycler and is not produced to a specification.

In order to produce fine powder below 1mm in size either a cryogenic milling process is required or a specialised ambient grinding process (such as a cracker mill). The feed material for these processes will vary but would generally be sub 5mm material from the process described above. This further grinding process "liberates" more of the metal and fibre contaminates therefore capable of producing a rubber powder that is over 99% free of metal and fibre. Tyre rubber is vulcanised and therefore the only way to remove metals and textiles is by a physical process, unlike thermoplastics the tyres cannot be melted and melt filtered. A small volume of truck and car buffings from the tyre retreading industry is available and is considered a premium feedstock as it has low levels of metal and fibre contamination.

This project has identified only a small number of companies capable of producing EOLVT fine rubber powder below 400 micron in size which is currently understood to be the most cost effective material to incorporate in thermoplastics. Finer materials are available via the cryogenic process but the additional cost of liquid nitrogen make these grades unattractive.

Quality /Specifications

In the UK, the Tyre Recovery Organization and WRAP have produced a standard PAS 107:2012 which sets out to define the type of rubber, size specification and levels of wire and textile contamination. It has not been widely adopted [11].

The industry generally classifies products by mesh size but there are differences between mesh sizes quoted for the heavy duty meshes used in production sieving machines and those used in laboratory equipment. Particle size analysis for any given grade is of greater relevance in terms of its suitability in a thermoplastic composite than a quoted mesh size.

In technical applications such as RubWPC a particle size specification is generally agreed between the fine rubber producer and customer. A product specification should also include the moisture, fiber and metal content.

Trade organisations

There is the European Tyre Recycling Organisation (ETRA) and a number of national tyre recycling organisations which provides a forum for developing the tyre recycling industry. None of these organisations have set mandatory quality standards [13].

3.3 Wood

Wood flour consists of a very fine particle size form of wood. It is manufactured by milling /grinding and sieving material derived from “virgin material” i.e. the wood has not been used for any other purpose. As such it is not a recycled material. One obvious reason for this is that a lot of timber products have chemical treatments to protect the wood from insect and microbial attack. These chemicals would potentially be dangerous if present during the heat processes used when manufacturing composites with plastics and rubber.

A number of the manufacturers of the grades used for compounding in thermoplastics supply similar materials to other manufacturing processes. They supply coarser grades for various types of animal bedding including grades for both domestic pets and farmed livestock.

The project could only identify a small number of wood flour manufacturers within the EU. The larger timber producing regions of the USA and Russia had a larger number of manufacturers.

Feedstock /Sources of material

The feedstock for fine wood flour is virgin timber, either softwood or hardwood varieties.

The species of trees that are commonly used to produce wood flour are white pines, aspen, spruce, maple, oak and cedar trees [14].

Process

In this respect the wood flour industry is similar to the rubber reprocessing industry where a large input material is downsized by mechanical grinding / granulation and sieving. In order to obtain very fine wood flour before the particle size reduction, the industry can have a pre stage where the wood is dried in order to facilitate the grinding process. After the grinding process, particles with different sizes can be obtained and also variation in particle shape and structure is common. The next stage of the wood flour processing is the sieving and screening process where the processor obtains the desired particle size distribution for the material. This stage can be done either by mechanical means or by air screening methods in order to have a narrow range of particle size distribution.

Quality /specifications

Wood by its very nature is variable in the properties that it has and therefore makes its use in products that have to meet a certain specification more challenging than other materials that are made from synthetic feedstock where the manufacturing process can be controlled.

The classification of the wood flour products available comes under the following headings:

- Softwood
- Hardwood
- Moisture level
- Particle size distribution and shape
- That it is form a sustainable source of timber.

Wood flour is not a standardized product and generally the quality of the wood flour is affected mainly by the raw material used. High quality wood flour comes from hardwoods due to high strength and durability of this type of wood. Low grades of wood flour usually come from softwoods. This can be attributed to the different composition of hard and softwoods. Softwoods usually have more sap content.

Review of the particle size distributions available indicates that manufacturers make specific grades for customers rather than there being an industry generic product offering.

In order to compound wood flour into thermoplastics, processors like Ecodeck have to incorporate drying equipment in their lines to ensure the moisture level is low enough not to cause manufacturing problems and issues such as voids in the final product.

Trade organisations

We could not identify a trade organisation for wood flour. A number of national bodies like the UK Forest Products Association (UKFPA) and the International Programme for the Endorsement of Forest Certification (PEFC) promote the use of timber from sustainable sources.

4 Conclusions

The European plastics recycling industry is effective in producing quality feedstocks from post industrial waste streams. The post consumer /packing waste streams are the largest and more challenging in terms of recycling.

The tyre recycling industry is very challenging primarily because tyres are complex cross contaminated items where it is difficult to separate the components. There are a limited number of producers of fine powders suitable for use in polymer composites.

The wood flour industry is based on virgin timber, there are a limited number of producers and the material is challenging simply because it comes from a natural feedstock that is inherently variable.

Regarding the quality of the recycled materials in all the industries the quality of the recyclates varies greatly. In the rubber and wood flour industries, these materials are not standardized and generally have low specifications. In these cases the quality is intimately related to the quality of the feedstock and to the effectiveness of the recycling process. For the plastics industry in the past few years there has been legislation created with the aim of standardizing recycled plastics in order to obtain a more consistent and better quality material.

5 Proposed development formulations

Taking into account the research done in the previous chapter it can be concluded that any proposed specification /material formulations for the new rubber: wood: plastic composite should meet the following general criteria:

1. The formulation will provide a practical composite material.
2. The project leader needs to decide whether any proposed formulation / composite should meet EN 15534-1:2014. This particular standard refers to wood: plastic composites, not rubber.
3. Any formulations should be processable on existing /industry standard plant and equipment in a cost effective way i.e. meet required output rates and energy costs.
4. Materials should be readily available from suppliers within the EU.
5. Materials should not have significant health and safety / handling issues.

In addition to the general considerations above, the proposed formulations have to take into account the technical and practical knowledge of rubber, wood and plastic composites of the partners in the project. In the development of a new product such as the RubWPC composite, a commercial evaluation should be included in order to ensure that the chosen formulations are cost effective. This does not necessarily mean cheaper than current practise but if a formulation is going to be more expensive it needs to deliver improved performance for the customer.

In terms of cost the current hierarchy is

1. Additives and processing aids	Highest
2. Polymer	↓
3. Rubber	
4. Wood	Lowest

Regarding the formulations currently used in commercial wood/ plastic composites, they range from:

55-60% (wt%) wood flour

35-40 % (wt%) thermoplastic

1-5% (wt%) additives /coupling agents

5.1 Proposed material specifications

Additives

Additives or/and coupling agents will be required in order to improve the mechanical performance of the final composite material. The type and amount of additives necessary to include in this formulation will be determined in D2.2 of this project.

Wood flour

The wood flour used in RubWPC formulation should be hardwood from virgin timber from PEFC certified sources. WPC composites can be either composed by hard or soft wood. Each type of wood will compound differently and will also give different appearance to the final composite material. .Current experience indicates that hardwood provides the best performance in current applications.

The wood flour should have a maximum moisture content of 8% (wt%) and a density of < $0.3 g/cm^3$.

Regarding particle size distribution, it should have a maximum of 2.5% retained on a 900 micron sieve and 16% retained on a 500 micron sieve.

End of life vehicle tyre rubber powder (*EOLVT)*

The crumb rubber powder should be derived from car tyre rubber, i.e. predominately SBR. If this is not available then a mixture of car and truck tyre should be considered. Ambient ground material is preferred to cryogenic material on the basis of cost and improved performance in composites.

The rubber powder moisture content should be less than 0.3% (wt%) and a density of 1.1-$1.2 g/cm^3$. Regarding particle size distribution, the smaller the particle size of the rubber better is the performance of the final material but we consider that “40 mesh powder” with a maximum of 5% retained on a 425micron sieve is acceptable for the formulation of the RubWPC composite.

Thermoplastic

The thermoplastic used in the formulation should be either a recycled high density polyethylene (HDPE) or a polypropylene (PP) co-polymer from a blow moulding grade.

The material will need to be reprocessed in an extruder with a melt filter to remove contaminants.

HDPE

Density: 0.95-0.96g/cm^3

MFI: 0.5-1.0 @ 21.6Kg/10min

PP

Density: 0.9-0.91g/cm^3

MFI 1-2 @21.6kg /10mins

5.2 Proposed development formulations

The proposed formulation for the RubWPC composite is presented on Table 2 and the materials should have the specifications presented on 5.1.

Table 2 Proposed formulation for RubWPC composite.

Material	Composition (wt %)		
Recycled HDPE or recycled PP	35-39	35-39	35-39
Virgin hardwood flour	50	40	30
Recycled EOLVT powder	10	20	30
Additives	1-5	1-5	1-5

Experience of the project partners suggests that a minimum of 40% thermoplastic and additives is required to form a matrix with the wood flour and rubber.

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