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WOOD PLASTIC COMPOSITES

FUTURE-PROOF MATERIALS FROM WOOD COMPOSITES – PROJECTS WITHIN THE "FACTORY OF TOMORROW" SUBPROGRAM

bmvit
Austrian Federal Ministry of Transport,
Innovation and Technology

In 1999, the Austrian Federal Ministry of Transport, Innovation and Technology (bmvit) launched the "Sustainable Development" research and technology program aiming to effectively support the restructuring process towards a sustainable economy through research. Various research and development projects as well as demonstration and diffusion measures, which will give new impetus to innovation in Austria's economy have since been supported within the scope of a number of subprograms. The "Factory of Tomorrow" subprogram aims to encourage trendsetting pilot projects in the field of sustainable technology development. Model examples include sustainable technologies and innovative manufacturing processes, the use of renewable raw materials or future-oriented products and services that concentrate on with a consistent focus on the usefulness of the product.

Wood Plastic Composites (WPC)

Composite materials based on a matrix of thermoplastic polymers, which are produced by means of a molding process and consist mainly of lignocellulose particles (e.g. wood, lignified plants).

T O P I C

MARKET POTENTIAL FOR NOVEL WOOD COMPOSITES

In recent years, the market for natural fiber reinforced plastics has seen a very positive development with growth rates of 25 %. In addition to hemp and flax fibers, which are primarily used in the automotive industries, the use of wood fibers in industries that are exposed to extreme price pressure (e.g. the construction sector) becomes increasingly attractive. While the main markets for ***wood plastic composites (WPC)*** are in the U.S.A. and in Japan, experts expect enormous growth rates in Europe in the next years as well.

Until recently, these wood plastic composites had a maximum wood content of 50 % and wood was used merely as a cost-efficient filler material. New technologies permit to further increase the wood fraction, thus making wood fibers an essential component of the formulation. Wood plastic composites with wood as main component and a low plastic content are processed predominantly by means of extrusion whereas injection molding is hardly used at present.

Main applications currently include profiles for trim, window profiles, doors, outdoor furniture, decking etc.

On account of their high wood content WPCs show a substantial price advantage compared to conventional plastics. The positive properties of wood, such as mechanical strength and stiffness, appearance and agreeable feel to the touch as well easy recyclability and simple disposal also contribute to the promising prospects on the market of these novel composites. Owing to the high proportion of renewable raw materials these new composites may be an important contribution towards a sustainable and resource-saving development.

Several research and development projects within the "Factory of Tomorrow" subprogram addressed the topic "Wood Plastic Composites".

Project 1

Wood Plastic Composites

(Cooperative project with technology development contributions from several enterprises)

- Neue Wertschöpfung aus Holzspänen (New value added from wood fibers)
- Entwicklung einer Holzspäne-direktdosierung (Development of a direct wood fiber dosing technology)
- Entwicklung eines Extrusions-werkzeugs (Development of an extrusion tool)

W. Stadlbauer, Erik Sehnal, Leopold Weiermayer

Project 2

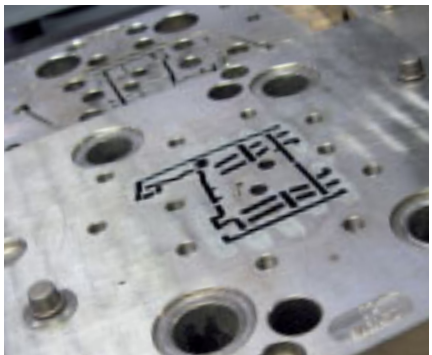
Modifizierte Holzspäne für höherwertige Holz/Kunststoff-Verbundwerkstoffe

(Modified Wood Chips For Improved Wood Plastic Composites)

Robert Putz

The cooperative project aimed to develop process and tool technologies as well as suitable formulations for high-content systems (i.e. more than 70 % wood fraction). The close cooperation between research institutions and Austrian enterprises made it possible to solve technological problems and to perform systematic investigations into the structure and properties of this new group of materials. Researchers succeeded in increasing the wood content of the composite to more than 80 %, thus making wood the main component of the material.

A follow-up project examined methods aiming to optimize the mechanical and physical properties of wood plastic composites through chemical modification of the wood fibers.



WOOD PLASTIC COMPOSITES – NEW TECHNOLOGIES FOR THE MANUFACTURE OF COMPOSITES WITH HIGH WOOD CONTENT

The common goal of the individual projects consisted in developing technologies for the manufacture of new materials from a mixture of wood fibers and a small fraction of thermoplastic polymers; the materials should have wood-like properties and, at the same time enable manufacturers to use conventional plastics industry technologies.

Objectives Of The Cooperative Project:

- Improving the value added of wood particles, which usually have been used only as by-products (pellets, particle board industry...)
- Systematic study of the property matrices of highly filled WPC formulations
- Optimizing formulations
- Optimizing wood fiber properties
- Developing a high-performance extrusion tool
- Developing a new direct dosing and feeding technology for the extrusion process
- Optimizing downstream processing technologies
- Developing a materials and technologies knowledge base for the manufacture of marketable products

RAW MATERIALS AND FORMULATIONS

Wood plastic composites can be manufactured from recycled materials. The plastic fraction consists of granular particles or agglomerate. The wood fraction is extracted from waste material supplied by the timber industry. The wood content of the composites determines possible applications as well as manufacturing methods.

At present, WPC production relies almost exclusively on four thermoplastics: Polyethylene (approx. 65 %), polyvinyl chloride (16 %), polypropylene (14 %), and polystyrene (5 %). The important thing is that the polymers have a relatively low melting temperature to minimize thermal stress on the wood component during the extrusion process.

Wood is used in different forms ranging from wood flour, to wood fibers with the most varied structures, to pellets. While pellets allow for easy feeding and dosing, they cannot be used for all purposes because the degree of their being "digested" in the extruder is not constant on account of the varying density of the pellets; this results in unstable quality levels of the finished product. The production process uses almost all additives known in the plastics industry, such as UV stabilizers, lubricants, heat stabilizers, etc. In addition, the process relies on so-called

"coupling agents", i.e. substances that improve bonding between the wood fibers and the plastic matrix.

Researchers tested almost 60 different formulations in order to explore the property profile of this group of materials. The polymer basis used consisted exclusively of polyolefines, the wood fraction was predominantly in the form of fibers and included different species of tree (e.g. spruce, pine, beech).

The test series varied the formulation parameters below:

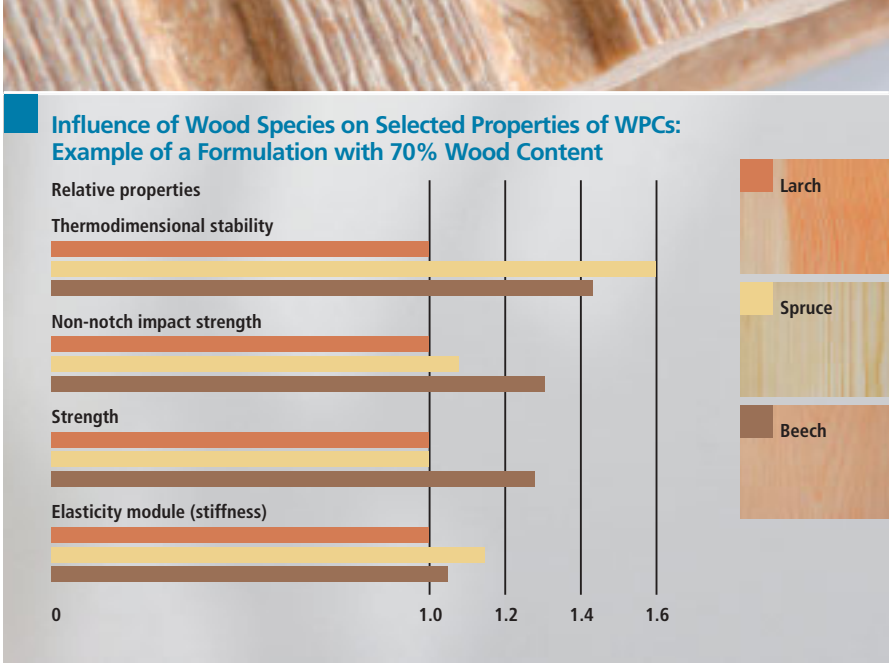
- Polymer type and content (between 18 and 28 %)
- Wood species and content (between 70 and 80 %)
- Coupling agent (type and concentration)
- Extrusion parameters (screw rpm and throughput)

A systematic examination of the wood fraction before and after extrusion served to identify the optimum fiber material. The examination aimed to identify the stress on wood fibers as a

Source: Project 1

Influence of Wood Content on the Properties and Potential Applications of WPCs

Wood content	Appearance	Preferred application	Properties	Extruder
70 – 90 %	„Woody"	Construction, not directly weathered, interior applications	High stiffness, low impact resistance, limited water fastness	Conical Twin-Screw Extruder, „Extrusion"
40 – 70 %	„Wood-like"	Outdoor applications	Good water fastness	Conical Twin-Screw Extruder, „classical extrusion"
5 – 40 %	„Plastic-like"	Profiles somewhat reinforced by the wood fraction		All extruders possible, „classical extrusion"



Source: Project 1

result of processing and to deduce the basic know-how for a standardization of wood particles. For this purpose, researchers drew a sample from the base material; after processing, the plastic fraction was removed by means of chemical treatment. Prior to extrusion, the three beech wood samples were clearly different as to their form. After extrusion, there was no significant difference between the three particles. The extrusion process had a homogenizing effect also with a view to wood fiber geometry. This shows that particle size is chiefly dependent on extruder parameters (screw size, screw geometry).

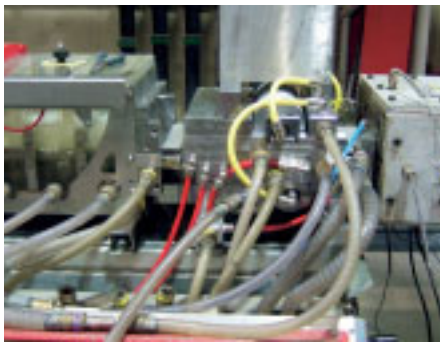
NEW DEVELOPMENTS IN PROCESS ENGINEERING

Today, the manufacture of wood plastic composites almost exclusively relies on extrusion. Extrusion is a process for the continuous production of profiles (hollow or solid profiles); the technology is also used in the production of granulate. One has to distinguish between direct extrusion (a one-stage process in which mixing of the various components and shaping of the profile is done in a single process in the extruder) and the extrusion of premixed feedstock (the first stage produces granulated feedstock, which is then formed into a profile in another extruder).

Important aspects of the overall project refer to the increase of cost-efficiency of profile extrusion and to the improvement of profile quality. Conventional process and tool technologies have, so far, not yielded satisfactory levels of profile quality and/or economically viable output rates. The participating industrial partners (Cincinnati Extrusion GmbH and Greiner Extrusionstechnik GmbH) have now succeeded in solving these technological problems within the scope of independent research projects.

Conventional WPC extrusion usually uses pellets that already contain both components – wood and plastic. In order to increase cost-efficiency and to avoid poor quality of the finished product, the project aimed to realize direct feeding of the wood particles into the extrusion process. This required further development of process and tool technology and the designing of equipment that makes it possible to process wood fibers and chips (e.g. from sawmills or from the particle board industry) together with several other components (e.g. additives or colorants) directly in the extruder in one operation. Suitable feedstock in this approach ranges from wood flour with very short fiber lengths to long fiber materials. The mixing ratio is between 50 % and 85 % wood content, humidity of the wood fraction is 0 % to 8 %. In addition to a cost reduction, the new equipment also afforded an increase in extrusion throughput.

The objective of the second part of the project consisted in the development of a new extrusion tool able to realize wall thicknesses of 2.5 to 6.0 mm. The pilot tool permitted to test various material systems ranging from larger wood particles to small wood fibers and with varying degrees of filling as well as to ascertain the influence of these parameters on the process and on the quality of profiles. The results from the test series show great technical and economic potential for numerous profile applications and complex profile cross sections. The projects also demonstrated that extruding high wood fiber content



material is feasible with a high degree of process safety. Newly developed gloss and cooling plate technologies permit adequate control of the profile surface.

The next step consisted in calculations for an actual building component (sole-plate profile for a prefabricated house) and in defining rough formulation guidelines for the production of this profile. On account of its special design, the profile manufactured by one of the project partners (Griffner-Haus AG) fulfills several functions. It may be used for, both, outer walls and (through separation of hollow chambers) interior walls. The long-term behavior of this profile is currently being tested in a display home.

PROJECT

MODIFICATION OF WOOD CHIPS FOR HIGH VALUE WOOD/PLASTIC COMPOSITES

Wood plastic composites combine the positive properties of wood (e.g. high strength) with the advantageous properties of plastics (permit production of complicated profile cross sections, minimum water uptake). However, with increasing wood content this new group of materials may be subject to problems typically associated with wood. These include water uptake, thus insufficient dimensional stability (swelling and shrinking) as well as fungus infestation.

The goal of a follow-up project within the "Factory of Tomorrow" subprogram consisted in changing the wood fraction through targeted chemical modification in order to optimize the mechanical and physical properties of wood plastic composites. This is to extend the range of applications for highly filled WPCs and make applications that were out of reach in the past feasible.

Laboratory testing of wood particle modification has been conducted on a broad basis. The treatment of spruce and beech particles involved, both, impregnation and chemical (reactive) modification methods. In this context, researchers for the first time tried a **new method, i.e. acetylation with isopropenyl-acetate.**

The researchers first performed tests on a pilot station scale (< 7 kg wood particles), and, based on these, larger scale trials (production of 700 kg modified wood particles). In this case, the new method was applied to spruce particles.

Subsequently, the researchers applied fracture mechanical tests, artificial weathering, and fungus tests and examined the WPCs produced by injection molding and extrusion – before and after production – as to mechanical properties, resistance to environmental impacts, water uptake, and dimensional stability.

The impregnation tests with wood particles did not show any improvement, concerning water uptake and dimensional stability nor with a view to mechanical strength.

The newly developed acetylation with isopropenyl-acetate, however, proved to be a technically feasible modification method offering various advantages for the process and the resulting products:

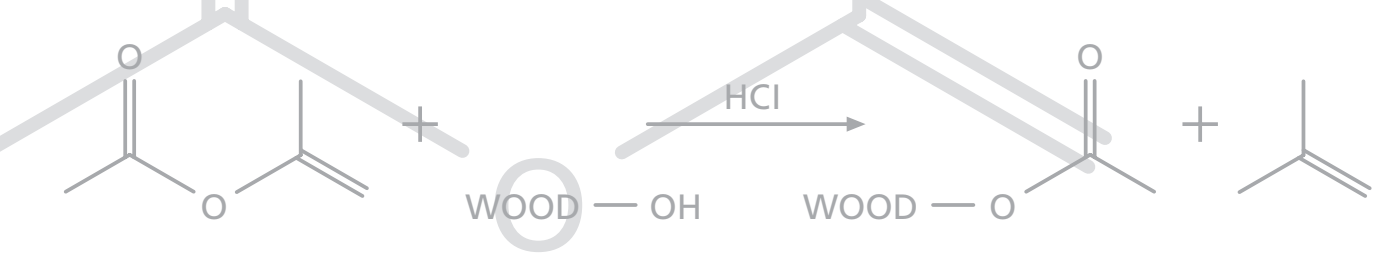
- Mild conditions of reaction
- The degree of acetylation needed for satisfactory fungus resistance is easily attained
- Acetone, a by-product of the reaction, can be easily removed

The WPCs treated by this method clearly showed improved properties compared to materials from non-modified fibers using equal formulations:

- Clearly improved flow properties during extrusion, thus allowing for higher extrusion speeds
- Up to 78 % reduced water uptake
- Significantly improved dimensional stability
- Improved fungus resistance

The new method thus permits to produce WPCs with high wood content that are suitable for special applications, e.g. in moisture-prone areas; this has not been feasible with the wood composites available so far.

There is need for additional research concerning the mechanical properties of these materials made from modified wood fibers because they showed some shortcomings compared to WPCs using unmodified fibers. New findings suggest that using alternative (or still to be developed) coupling agents will result in enhanced mechanical properties.



COOPERATIVE PROJECTS AND FURTHER RESEARCH

The projects contributed to the establishment of close relations between research institutions and industrial businesses. This resulted an ideal combination of expertise from the fields of process engineering, wood chemistry, and plastics.

Industrial partners included IFN Internorm Bauelemente GmbH & CoKG, Cincinnati Extrusion GmbH, Greiner Extrusionstechnik GmbH, Trodat GmbH, and GriffnerHaus AG. The scientific project partners comprised the Institute of Wood Science and Technologies at the University of Natural Resources and Applied Life Sciences Vienna, the Department of Polymer Sciences at Johannes Kepler University Linz, and, as project coordinator, the Transfercenter for Polymer Technology at the Upper Austrian Research Center Linz.

The project yielded valuable new findings concerning formulation-property relationship, influence of process conditions on WPC properties as well as composite and raw material characterization. The cooperation between research and the economic sector also established a network in the WPC process chain, which will be very useful beyond the duration of the projects.

In order to be able to perform its R&D activities and also continue them after completion of the project, the Transfercenter for Polymer Technology invested money for the pilot station infrastructure in time (fiber extruder Cincinnati Fiberex T58 with complete downstream equipment – calibration, take-off, saw, tilting table by Greiner Extrusionstechnik). The projects within the "Factory of Tomorrow" subprogram constituted the starting point for more than 15 new projects that also addressed the topic of natural fiber reinforced plastics. In addition, more than 40 follow-up orders for formulation and process optimization by Austrian and international customers have been placed or have already been carried out.

Numerous follow-up projects aim primarily at the development of formulations for specific products. Another research focus consists in improving the ductility of WPCs while maintaining stiffness of the material.

The results of the "Factory of Tomorrow" projects establish the technological and economic prerequisites for a successful introduction on the market of this new group of materials.
Thus, Austria has further strengthened its position in the field of natural fiber reinforced plastics.

PROJECT PARTNERS

Wood Plastic Composites
Neue Wertschöpfung aus Holzspänen
Entwicklung einer Holzspänedirektdosierung
Entwicklung eines Extrusionswerkzeugs

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Modifizierte Holzspäne für höherwertige Holz/Kunststoff-Verbundwerkstoffe
Robert Putz,
Kompetenzzentrum Holz GmbH
Linz 2006

INFORMATION PUBLICATIONS

The final reports on the abovementioned studies will be published in the bmvit series "Reports on Energy and Environment Research".
Project 1: 68/2006
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