Final report

Reed Canary Grass for composite applications

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Part 1: Abstract

Reed canary grass (RGC) a perennial grass with high production of biomass that grows in boreal zones has been investigated for use in composite applications. The focus has been to increase the value of the grass that is today mainly is used for animal bedding. RCG's economical potential, composition, suitability for extrusion to thermoplastic composite pellets, their mechanical properties, suitability for injection moulding as well as the manufacturing a prototype product has been carried out. Nanocellulose has also been extract from RCG. The mechanical properties of RGC/thermoplastic material show results in the range obtained by other biomass composites, in particular are on a par with wood polymer composites (WPC) currently used in many applications such as decking and fencing. Injection moulded parts produced from RCG proved that manufacture products is straightforward and some products currently made of 100% thermoplastic material can be switched to a blend of RGC/thermoplastic thus providing great environmental and economic advantages. The nanocellulose isolated from RCG produced networks with high yield strength and low permeability compared to other sources indicated that it could be utilised to improve the barrier properties in different applications for example in the food and packaging industry.

A large range of results have been produced in the project which will be useful for further the implementation of RCG in composites.

Projekt har fått finansiering genom:
Stiftelsen Lantbruksforskning

Part 2: Report

Introduction

Reed canary grass (Phalaris arundinacea L.) is a perennial, rhizome-building C3 grass with high production of biomass that grows in boreal zones. The grass can grow up to 2 meters per year and is grows wild in most parts of Sweden. In the 18th and 19th century reed canary grass (RCG) was studied as fodder and still used today however it was found that it was not suitable when it is fully grown and dried. RCG dries naturally on the fields and no additional drying process is needed. During the last 30 years researchers and farmers have focused on the use RCG as a solid fuel. However, when biofuel market prices started to fall in 2011, farmers needed to find other uses and new markets for RCG. Currently, the most common utilisation is animal bedding material in stables and barns.

Currently, about 800 hectares of reed canary grass are established and cultivated in Sweden. There is lots of unused farmland in Sweden suitable for reed canary grass. Many landowners are therefore interested in RCG, which have potential for significant biomass production. One major obstacle for the development in Sweden so far has been the lack of profitable business opportunities; therefore it is important to find new utilization for this kind of crop. Conversion from fossil to bio-based economy requires new raw materials and product development. There is a high value in finding profitable chains of production for reed canary grass.

Natural fibres and regenerated cellulosic fibres is an important element of fibre production around the world and new raw material resources are of interest. Cellulose makes up around half of all solid material in the plant world. It is abundant and renewable, and is therefore an almost inexhaustible raw material resource. Cellulose based materials is a potential replacement for many of the finite resources used today. Usually the raw material is wood which grows relatively slow and is fairly expensive. Wood is also in high demand for use in a range of other products which can benefit other crops can have both ecological and economic.

The project aims to increase the value of the reed canary grass, which today mainly is used for animal bedding, by finding higher value application. The main application focus of the project is to use reed canary grass for composite applications.

Production and possibilities

Environmental

The main advantage of perennial grasses is the possibility to harvest every year, giving higher biomass per hectare production. The rotation period is a lot shorter than for biomass from forests, which means that when a society in the near future need large amounts of new raw material for environmental friendly products, potentially replacing fossil ones based ones, it can exploit plants such as reed canary grass. There are plenty of benefits concerning reed canary grass, such as the viability, good harvest on most soil types every year, energy efficiency due to at least 10-15 years before reseeding, cultivation with conventional farming machines and several alternatives for management depending on the end use of the material.

RCG gives a high biomass yield even in a sub-arctic climate. The biomass production reaches 6-8 tons dry mass per hectare spring collected and 8-10 tons in autumn (Finell 2003). A delayed harvest system has been evaluated. The harvest is delayed until the growth season has ended and the straw of the plant has died, which in Sweden means until spring the year after the growing season (Landström et al 1996). The delayed harvest system for RCG is economically viable on marginal land with a minimum environmental impact compared to conventional crops (Pedersen, 1997).

Economical

Swedish farmland has decreased with 472 400 hectares during the last 50 years. More than 1 million hectares have been abandoned since beginning of the 1940’s when Sweden had all time high in food and fodder cultivation. Consequently there is a big potential for biomass production on unused land. A production every spring of at least 500 000 tons dried raw material is possible to utilise in high value materials.

The use of local renewable agricultural or wood-based raw materials in the production of bio-based components and composite products has been a trend to promote local/regional economic development. The production chain of such applications is testified to be able to create a large range of jobs. For instance, Brazilian supplier of Mercedes Benz uses locally produced coconut fibres for the production of headrests and car seats. Sweden with its vast renewable resources, however, does not have any equivalent production. Sweden has great opportunities to realize such production based on Reed Canary Grass if the knowledge chain is completed.

Development of composites from RCG

Extraction and characterisation of nanocellulose from RCG

One of the goals of this project has been to extract cellulose fibres and nanofibers from RCG. Content of cellulose, lignin and hemicellulose of this grass were determined during the extraction process. Morphology and crystallinity of the purified cellulose, which have great influence on the morphology and structures of cellulose nanofibers and nanocrystals, was also investigated.

The possibility of producing cellulose nanofibers (CNF) from RCG was investigated using an ultrafine grinder. The energy consumption during the mechanical treatment and quality of the nanofiber from RCG was measured to evaluate the production of CNF as a value added product from the grass. A characterization of the produced cellulose nanofibers was performed using methods such as Scanning Electronic Microscopy, Atomic Force Microscopy, Raman Spectroscopy and X-Ray Diffraction. Networks of nanocelulose - nanopapers - were produced from the obtained fibers and the samples were mechanical tested. Manufacturing of CNF composites using Resin Transfer molding was tested.

High quality nanofibers were successfully produced from Reed Canary grass. Networks of tightly packed CNF were produced that had higher yield strength and similar modulus and ultimate strength compared to nanofibers isolated from birch pulp. As showed in Figure 1, the ultimate strength in each case is similar and the most noticeable differences are in the yield strength and strain. RCG present higher values for yield strength in contrast with Birch. However, the strain in Birch nanofibers had a larger plastic deformation zone. The difference in the mechanical behaviour in the networks could be related to the chemical composition in the fibre from Birch and RCG. The composition is obtained by first removing extractives, which is material in a biomass sample that is soluble in either water or ethanol, typically fatty acids, resin acids, and sterols. The chemical composition obtained in the RCG bleached pulp compared to Birch pulp is shown in Table 1. The RCG had low values of hemicellulose and lignin, however, a higher content of extractives was found when compared to Birch. It is possible that the presence of extractives that could represent a change in the final properties of the CNF networks produced, though since the pulp is washed and bleached before grinding, this is unlikely. The differences may be instead due to the higher mineral content in RCG compared to birch (Saijonkari-Pahkala, 2008). Alternatively, some studies show that low content in lignin has been related with better paper properties. (Bidin et al, 2015; Alila et al, 2013)

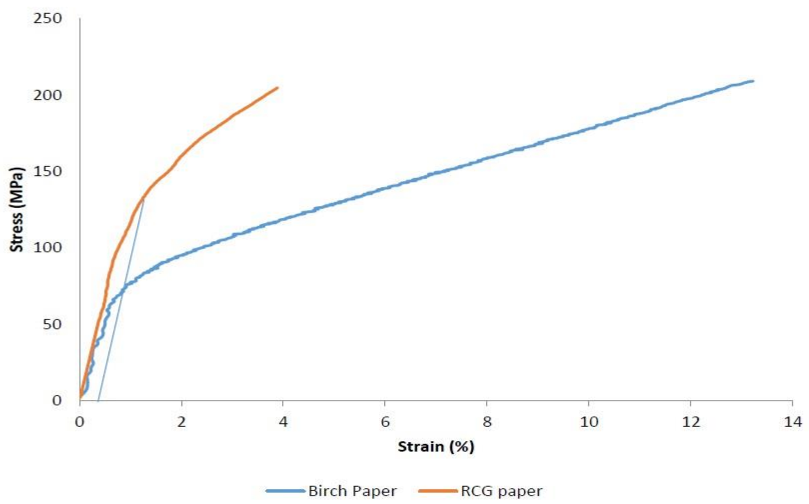

Figure 1. Stress versus strain curves from RCG and Birch nanofibers

Table 1. Comparison of chemical composition, in percentage [%], between Birch and RCG pulps.

	Cellulose	**Hemicellulose**	**Lignin**	**Extractives**
RCG Pulp	79,9	6,5	2,6	11
Birch Pulp	70	21	5	4

The mechanical properties of the CNF (from RCG) networks improve with the grinding time. The improvement in the properties can be caused by the increasing content of CNF that could produce more bonds between the fibers (because of the higher surface area) and therefore homogenize the interfiber packing. Hence, CNF production from RCG resulted in a slightly higher, but significant, energy consumption compared to the reference material birch (see figure 2). The mechanical properties show that there is an optimal point of fibrillation and further fibrillation leads to a decrease in properties.

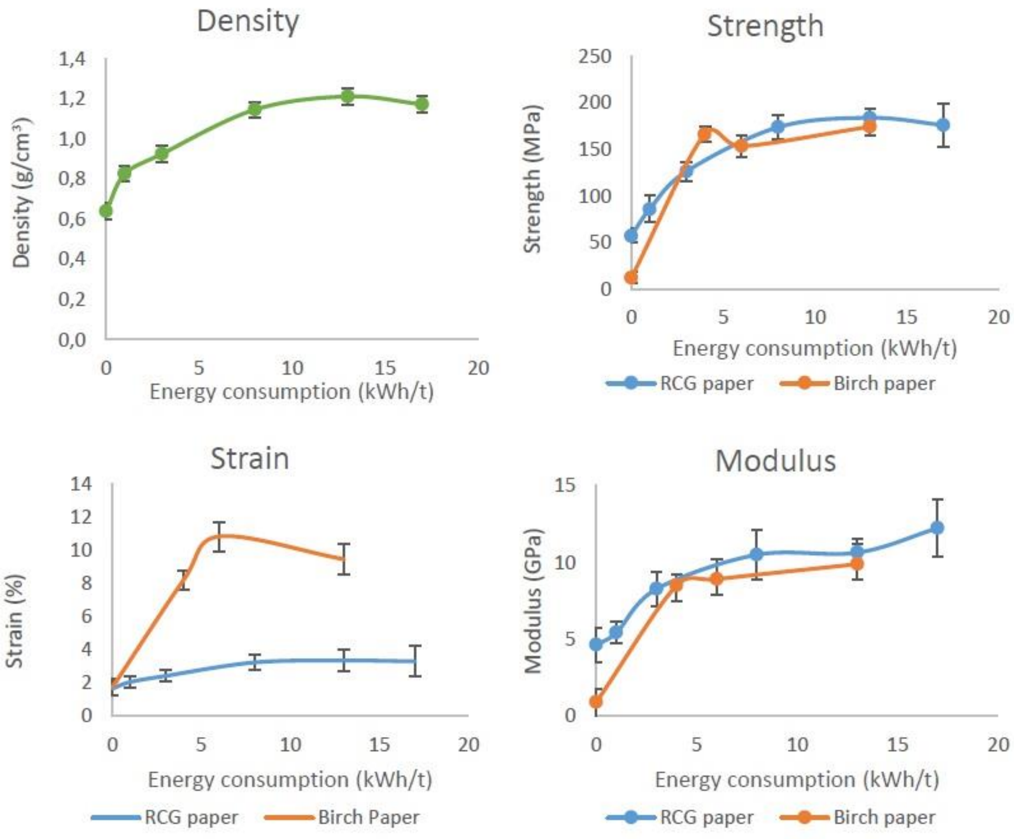

Figure 2. Mechanical properties and energy consumption of RCG and Birch nanofibers, errorbars represents one standard deviation.

The manufacturing of composites using RCG fibers networks with Prime LV epoxy was not possible due to the low permeability in the RCG networks. In general, the impregnation was poor and this can be related to the low permeability in the networks. Some issues with the demoulding were found, the layer used to spread the resin in the process was strongly attached to the composite and fewer layers mean a worse outcome during the peel off. A mechanical perforation was tested to improve the impregnation in the networks, but the improvement was not enough to produce an adequate composite. The low permeability of the nanopapers from RCG give a first indication of other applications where low permeability is important, such as packing material for food etc.

Fibre structure and possible long fibre design

Due to the lack of previously research on Reed canary grass as a fiber material for composites a comparison was made with other natural fibers from stalk and stems traditionally used, like flax and jute. The objective was to see if there is any possibility to use RCG as long fiber reinforcement in composites. The raw material and fiber structure of RCG was investigated to see what kind of manufacture technique that's applicable. The material has been studied microscopically for evaluating properties such as fiber composition, surface and inside structure. A literature study was made for estimating potential processing and use of the fiber.

The structure and composition of the fibers that can be seen in Reed Canary grass were found to be different from those in bast fibers such as flax and hemp. The fibers possible to extract from the crop are too short for spinning into yarn or for making non-woven mats with sufficient structural integrity. The fibers from Reed canary grass is therefore not possible to use for textile applications in their natural condition.

The research on Reed canary grass as a fiber raw material has mainly been on in the paper pulp production but not for applications like fabrics and composites. There are many reports on agricultural crops as a promising material for the pulp industry. The most common pulping methods for non-wood raw materials are soda-AQ and Kraft pulping (Finell 2003) and studies have been made on pulping of Reed canary grass with these methods (Finell & Nilsson 2004; Feng, & Alén 2001). Pulp mass can be refined into dissolving pulp which man-made or regenerated cellulosic fibers can be made from. Research on agricultural crop waste like sugar cane and cornstalks to produce dissolving pulp have showed positive result (Andrade & Colodette 2013; Behin & Zeyghami 2009) and fibers produced with the lyocell-process have successfully been made from sugar cane (Costa et al 2012). It would be also possible to use Reed canary grass in this way i.e. for the production of dissolving pulp, and thus it can to be used as for producing continuous fibers for textile and composite materials. With improved technology, non-wood species may be used instead of fibres originating from wood. Reed canary grass is an interesting material for dissolving pulp and the possibilities to make regenerated fibers from it will result in value adding products.

Injection moulded materials from RCG

The objective for this study has been to demonstrate the potential of Reed Canary grass as reinforcement in thermoplastic composites. The processability of different RCG raw material (straw, pellet and briquettes) was evaluated in the manufacturing method injection molding. Tensile, flexural and impact properties have been characterized. Seven different extruded and injection moulded materials were manufactured. Five materials were manufactured with polypropylene (PP) to evaluate which type of fibre raw material that were most compatible and had the best set of properties. After evaluation of the first five materials, two additional materials were manufactured, one with PP and one with polylactic acid (PLA). For these materials the screw design in the extruder were modified to get finer particles from the RCG straw than in the first setup.

The fully biobased composites from RCG/PLA shows the absolute best properties when it comes to strength and modulus and the properties are similar to PLA/wood flour composites with 30% filler (Peltola et al 2014). The most success RCG/PP composite based on tensile and flexural tests were those made from when the RCG was simple shredded straw before adding it to the extruder. In comparison with injection molded Jute/PP composites the values for RCG/PP in tension and 3-point bending were lower. This can be explained by the difference in fineness of the fibrous material. The whole stem from RCG is used in the process and contains larger parts than the jute yarn. Presumably, some parts from the RCG stem are not shredded into sufficiently fine particles which affect the results on the mechanical behavior. This theory is supported also by the fact that the additional shredded straw shows the best set of properties when compared to using the pelletized RCG.

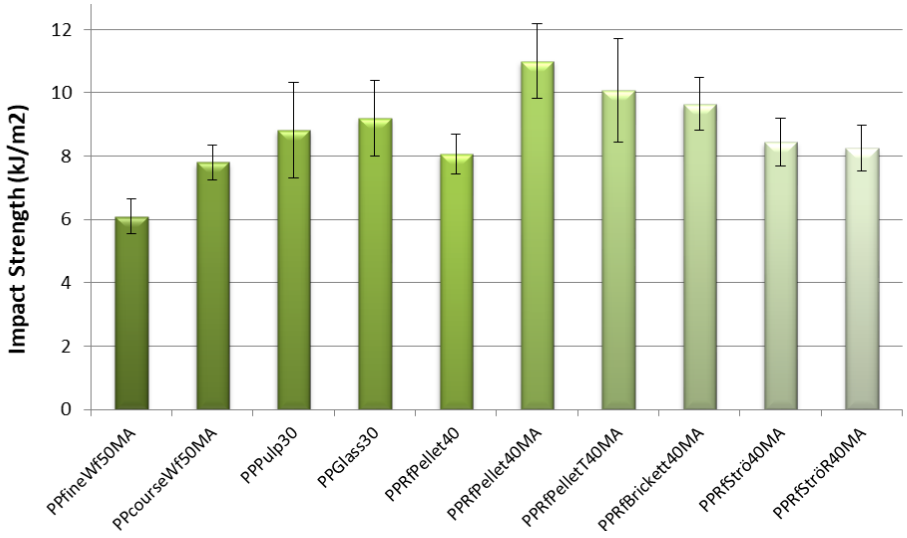

Figure 3. Impact strength of RCG composites compared to other biobased composites, errorbars represents one standard deviation.

The results of the impact tests showed that the impact strength of the RCG composites is was similar and in some cases better than PP composites with wood flour, pulp mass and glass fibre, see Figure 3.

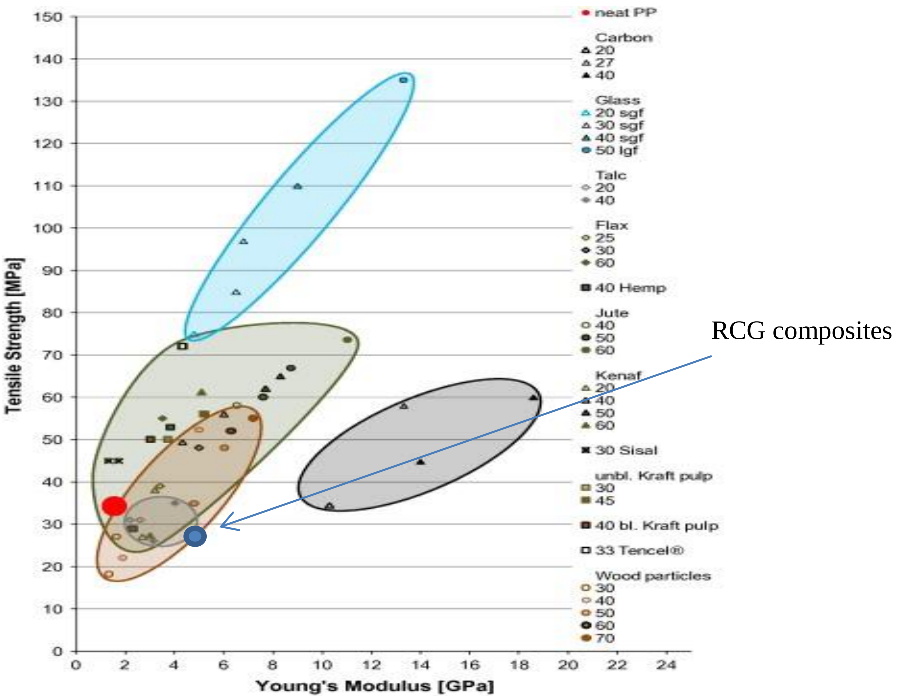

Figure 4. Tensile strength verse modulus for different PP composites from Sobczak et al 2012 together with the results of this report for RCG.

In summary, the RCG materials are straightforward to extrude, which is one of the most common method of producing short-fiber thermoplastic composites. The resulting composite shows properties comparable to other bio based raw materials (See figure 4), which given that the fibres are made from directly shredded straw rather than processed yarn, as in the case of flax, hemp, glass and carbon.

Demonstrator

As a demonstrator product for the project an outdoor cup (kåsa) was injection moulded from PP/RCG. The material shows promising properties and the environmental and economic benefits make it an interesting material in commercial products. The industry has shown an interest to implement the material in products where it can lower the price and have environmental benefits compared to other materials.

Summary and conclusion

In spite of the increasing applications of natural fibres, such as flax, jute and hemp, etc. in composite production, reed canary grass as a source for composite components has been little investigated. This project has showed that Reed canary grass can be used to produce composite materials with properties on a par or better than with wood flour and other naturals fibre based composites, but requires little pre-processing especially compared to other blast fibres or even glass. RCG grows well on pour soils and in harsh climate and doesn't need any further processing after harvesting. This makes it to a sustainable and economically competitive raw material as fiber reinforcement. A large range of results have been produced in the project which will be useful for further implementation of RCG in composites.

References

Alila, S., Besbes, I., Vilar, M. R., Mutjé, P., & Boufi, S. (2013). Non-woody plants as raw materials for production of microfibrillated cellulose (MFC): a comparative study. Industrial Crops and Products, 41, 250-259.

Andrade, Marcela Freitas, & Colodette, Jorge Luiz. (2013). Dissolving pulp production from sugar cane bagasse. Industrial Crops & Products, 52, 58-64.

Behin, J., & Zeyghami, M. (2009). Dissolving pulp from corn stalk residue and waste water of Merox unit. Chemical Engineering Journal, 152(1), 26-35.

Bidin, N., Zakaria, M. H., Bujang, J. S., & Abdul Aziz, N. A. (2015). Suitability of Aquatic Plant Fibers for Handmade Papermaking. International Journal of Polymer Science, 2015.

Costa, Sirlene M., Mazzola, Priscila G., Silva, Juliana C.A.R., Pahl, Richard, Pessoa, Adalberto, & Costa, Silgia A. (2012). Use of sugar cane straw as a source of cellulose for textile fiber production. Industrial Crops & Products, 42, 189-194.

Economic feasibility of the start-up of a biorefinery facility: a case of an integral production process. Bioenarea-Improve regional policies for bio-energy and territorial development. INTERREG IVC-Innovation & environment regions of Europe sharing solutions, activity 4

Feng, Zhinan, & Alén, Raimo. (2001). Soda-AQ pulping of reed canary grass. Industrial Crops & Products, 14(1), 31-39.

Finell, Michael (2003). The use of reed canary-grass (Phalaris arundinacea) as a short fibre raw material for the pulp and paper industry. Diss.(summary) Umeå : Sveriges lantbruksuniv., Acta Universitatis agriculturae Sueciae. Agraria, 1401-6249 ; 424
ISBN 91-576-6458-7

Finell, Michael, & Nilsson, Calle. (2004). Kraft and soda-AQ pulping of dry fractionated reed canary grass. Industrial Crops & Products, 19(2), 155-165.

Christou. M. The terrestrial biomass: formation and properties (crops and residual biomass). EU FP-7: Eurobioref.

Landström S, Lomakka L, Andersson S. Harvest in spring improves yield and quality of RCG as a bioenergy crop. Biomass Bioenergy 1996, 11, 333-341.

Pedersen S. RCG for pulp and biofuel. Economic viability and market possibilities. In: N. El Bassam, R.K. Behl, B. Prochnow. (Eds), Sustainable agriculture for food, energy and industry. Proceedings of the International Conference held in Braunschweig, Germany, June 1997, James & James (Science Publishers) Ltd., pp. 793-798.

Peltola H, Pääkkönen E, Jetsu P, Heinemann S, Wood based PLA and PP composites: Effect of fibre type and matrix polymer on fibre morphology, dispersion and composite properties, In Composites Part A: Applied Science and Manufacturing, Volume 61, 2014, Pages 13-22.

Saijonkari-Pahkala, Katri. "Non-wood plants as raw material for pulp and paper." (2001). PhD Thesis, University of Helsinki, Helsinki.

Sobczak, Lukas, Reinhold W. Lang, and Andreas Haider. "Polypropylene composites with natural fibers and wood–General mechanical property profiles." Composites Science and Technology 72, no. 5 (2012): 550-557.

Part 3: Publication/Communication of results

Scientific publications	
Other publications	Newspaper article in "Landsbygd i Norr"
Oral communication	Nanocellulose from reed canary grass: Processing, characterization and potential for nanocomposites, Yvonne Aitomäki, Violeta García Masabet, Guan Gong and Kristiina Oksman, InProc. 28th SICOMP Conference, Piteå, Sweden Jun 1-2, 2017
	Seminars in Nybro and Kalix, oral presentation and meeting with industry, small business owners and farmers.
Student work	Nanocellulose from reed canary grass: processing, characterization and composites, Project thesis Violeta García Masabet 2016
Other	SICOMP E-news #47
	The "Kåsa" has been used at meetings with customers with similar research interest
	E-mail to Reed canary grass farmers
	Flyers
	News and information at www.hushallningssallskapet.se, www.rörflenodlarna.se and www.bioenergiportalen.se.