Holz als Roh- und Werkstoff (2005) 63: 388–389
DOI 10.1007/s00107-005-0002-y

KURZORIGINALIA · BRIEF ORIGINALS

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Thermal behaviour of polysaccharides in wood during friction welding

1 Introduction

This paper deals with the joining of wooden pieces without any additional material, using the technology of friction welding. Sutthoff et al. (1996) made the first attempts for the joining of wood by means of friction welding in Germany, resulting in a first patent. Since the year 2000, the *Chair of Timber Construction (IBOIS)* at the *Swiss Federal Institute of Technology* in Lausanne is studying and developing this method for wood connection (Gliniorz and Natterer 2000, Gliniorz et al. 2001) in collaboration with the *Wood Research Munich*. The times necessary to complete a bond are shorter than one minute. No preparation of the welded surfaces is required.

Chemical analysis was carried out to determine the thermal reactions taking place during the welding process. This article deals with the thermal decomposition and the behaviour of the polysaccharides of wood in a temperature range from ambient temperature to about 450 °C, which is representative for the welding process.

At the beginning of the welding process, Coulomb-friction causes the interface to heat up. After a few seconds (3–10 s) at a temperature of about 320–350 °C the surfaces start to decompose in consequence of the increased temperature. The wood adjoining to the rubbed surfaces starts to soften, forming a viscous film. At about 420–450 °C a maximum temperature is reached and a steady state is attained. A final cooling down after the termination of the frictional movement leads to solidification of the interfacial film forming the connection.

2 Material and methods

2.1 Samples

The chemical analyses were carried out with Norway spruce (*Picea abies*) samples taken at different stages of thermal decomposition:

- Native wood of Norway spruce as **reference**
- Start of thermal decomposition at about 320–350 °C (**DS1** (**D**ecomposition **S**tage 1))
- Transient phase at about 350–380 °C (**DS2**)
- Steady-state phase at about 420–450 °C (**DS3**)

All samples were ground by a ball mill.

2.2 Methods

2.2.1 Extraction

The extraction of the samples was carried out at room temperature with acetone as solvent with all the test samples. This treatment shows the way in which the solubility of wood compounds increases as a consequence of thermal attack due to the frictional heat generation.

2.2.2 Analysis of polysaccharides after hydrolysis by means of ion-exchange chromatography

The hydrolysis of the *extracted* samples with trifluoroacetic acid according to Fengel and Wegener (1979), leads to a splitting of the macromolecules into their monomer components. The hydrolysis was carried in a thermo-block at 110 °C with different concentrations of TFA. The dried hydrolysates were solubilised in a defined volume of distilled water. The samples prepared in the manner described, were analysed in respect of the composition of polysaccharides by means of their monomer compounds by means of ion-exchange chromatography.

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3 Results and discussion

The amounts of extract content of the different samples obtained by extraction with acetone are shown in Table 1.

Table 1 Amounts of acetone extracts
Tabelle 1 Mengen der Acetonextrakte

Sample	Acetone Extract [%]
Reference	2.3
DS1	2.7
DS2	4.5
DS3	15.8

The amount of acetone extract increases with an increase of temperature. The highest increase occurs between **DS2** at about 350–380 °C and **DS3** at about 420–450 °C. The big difference between the two amounts of extract is due to a partial splitting of the polymeric compounds by the thermal influence. The most significant decomposition takes place between 350 °C and 450 °C. This is indicated by a higher solubility of the joint material in acetone in comparison to native wood.

The proportions of the different saccharides were found by different kinds of hydrolysis carried out. Not any kind of hydrolysis is ideal for every polysaccharide. The glycosidic bonds of xylan for instance are more susceptible to acidic attack than those of other polyoses. Thus, an amount of xylan is already decomposed to smaller units than monomers and cannot be retraced, while other polyoses are perfectly split into their monomeric compounds. An exact analysis requires optimised hydrolysis conditions, adapted to the different polymeric compounds. As the proportions of hexuronic acid and acetyl groups have not been determined during the analyses carried out, the total amounts of polyoses in the reference samples are not as high as given by the relevant literature.

The results of the sugar analyses are presented in Fig. 1.

The percentage of polyoses decreases steadily with increasing temperature. The decomposed wood, which is finally serving as interconnecting medium, contains 4.5% of polyoses compared to 25.9% in the reference sample. Thereby, the thermally less stable xylan is more affected than mannan. The strongest decomposition of polyoses takes place in the temperature range between 320 °C and 380 °C. The very short duration of the process (10 to 20 seconds) moves the thermal decomposition of wood compounds to higher temperatures in comparison to bibliographical data concerning the thermal degradation of wood (Fengel and Wegener 1984, Wienhaus 1999). Nevertheless, the order in which the different polymeric compounds of wood become decomposed stays the same. Due to their structural characteristics, cellulose and lignin behave thermally more stable than polyoses. The amount of cellulose stays nearly the same and rises somewhat due to the thermal decomposition of the other compounds.

Microscopical examinations (Stamm et al. 2005) of the contact zone showed that the interfacial material resembles a dense amorphous mass, containing fragments of wood cells. These wood cells, still showing the cell wall structure, are less decomposed than the amorphous material in which they are embedded. Thus, the polyoses detected at the interfacial layer are assumed to be mainly part of these cell wall fragments.

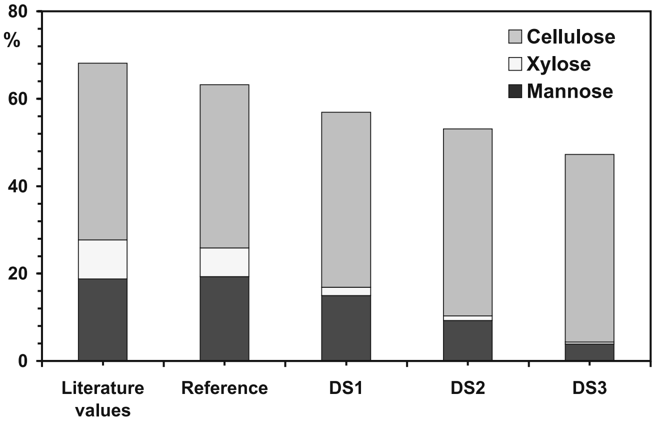

Fig. 1 Average values from repeat determinations of the monomeric sugar-units converted into anhydro sugars for different stages of thermal decomposition[1,2], literature values from Fengel and Wegener (1984)
Abb. 1 Mittelwerte der monomeren Zuckereinheiten aus Doppelbestimmungen, umgerechnet in Anhydrozucker zu verschiedenen Stufen des thermischen Abbaus[1,2], Literaturangaben nach Fengel and Wegener (1984)

Further papers will treat the behaviour of wood with regard to friction welding in a more extensive manner.

References

Fengel D, Wegener G (1979) Hydrolysis of polysaccharides with trifluoroacetic acid and its application to rapid wood and pulp analysis. In: Brown Jr RD, Jurassek L (eds) Hydrolysis of cellulose; mechanisms of enzymatic and acid catalysis. Adv in Chem Series, no 181. Am Chem Soc, Washington, pp 145–158

Fengel D, Wegener G (1984) Wood – Chemistry, Ultrastructure, Reactions. Walter de Gruyter, Berlin New York

Gliniorz KU, Natterer J (2000) Holzschweißen – Innovative Verbindungstechnologien im Holzbau. Tagungsunterlagen, Symposium der Ligna Plus/Weltmesse für die Forst- und Holzwirtschaft in Hannover, pp 9–18

Gliniorz KU, Mohr S, Natterer J, Navi P (eds) (2001) Wood Welding. In: Proceedings of the First International Conference of the European Society for Wood Mechanics, Lausanne, Switzerland, pp 571–574

Stamm B, Natterer J, Navi P (2005) Joining wood by friction welding. Holz Roh Werkstoff (in press)

Sutthoff B, Franz U, Hentschel H, Schaaf A (1996) Verfahren zum reibschweißartigen Fügen und Verbinden von Holz. Patentschrift DE 196 20 273 C2, Deutsches Patent- und Markenamt

Wienhaus O (1999) Modifizierung des Holzes durch eine milde Pyrolyse – abgeleitet aus den allgemeinen Prinzipien der Thermolyse des Holzes. Wiss Z U Dresden 48:17–22

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[1] Mannan as galactoglucomannan. Mannose, galactose and glucose were analysed, glucose (in the ratio mannose:glucose 3:1) was subtracted from the total proportion of glucose. The residue accounts for celluloses.

[2] Xylan as arabino-4-O-methylglucoronoxylan. Xylose and arabinose were analysed. 1.8% of uronic acid was added as found in relevant literature [1].