Proceedings in Engineering Mechanics
Research, Technology and Education

Lucas F. M. da Silva
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Klaus Dilger *Editors*

3rd International Conference on Industrial Applications of Adhesives 2024

Selected Contributions of IAA 2024

Springer

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ISSN 2731-0221 ISSN 2731-023X (electronic)
Proceedings in Engineering Mechanics
ISBN 978-3-031-69502-5 ISBN 978-3-031-69503-2 (eBook)
https://doi.org/10.1007/978-3-031-69503-2

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This volume of the series *Proceedings in Engineering Mechanics—Research, Technology and Education* contains selected papers presented at the 3rd International Conference on Industrial Applications of Adhesives 2024 (IAA 2024), held in Cascais (Portugal) during March 7–8, 2024. The goal of the conference was to provide a unique opportunity to exchange information, present the latest results as well as to discuss issues relevant to industrial applications of adhesives.

This conference is held every 2 years. The conference is chaired by Lucas F. M. da Silva and co-chaired by R. D. Adams (University of Oxford, UK), Chiaki Sato (Tokyo Institute of Technology), and Klaus Dilger (Technische Universität Braunschweig, Germany). The focus is on applications of adhesive bonding in the industry such as automotive, aeronautic, railway, marine, energy, and electronics. The idea is to bring together the adhesive makers and the adhesive users to exchange experiences and facilitate potential synergies and partnerships. 61 papers were presented by researchers from 14 countries.

In order to disseminate the work presented at IAA 2024, selected papers were prepared which resulted in the present volume. A wide range of topics are covered resulting in eight chapters dealing with formulation of adhesives (one chapter), pressure-sensitive adhesives (three chapters), adhesive properties (one chapter), design of adhesive joints (two chapters), and durability of adhesive joints (last chapter). The book is a state of the art of industrial applications of adhesives and serves as a reference volume for researchers and graduate students working in the field of adhesive bonding.

The organizers and editors wish to thank all the authors for their participation and cooperation, which made this volume possible. Finally, I would like to thank

the team of Springer-Verlag, especially Dr. Christoph Baumann and Ute Heuser, for their excellent cooperation during the preparation of this volume.

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July 2024

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Blend Technology to Enable Lignophenolic Resins on Industrial Scale

Peter Bliem, Wilfried Sailer-Kronlachner, and Hendrikus W. G. van Herwijnen

Abstract Lignin is the structural substance of wood or woody plants and accounts for approximately 30% of all non-fossil organic carbon on Earth. In paper industry, technical lignin is produced in large quantities, either as kraft lignin or lignosulfonate, depending on the process. The largest part of the obtained technical lignin is however burned for energy recovery. Furthermore, lignin is also obtained as organosolvlignin in biorefineries, albeit still in pilot scale only. As a biopolymer composed of phenolic components, lignin has a structural similarity to synthetic phenol–formaldehyde resins. The substitution of components of such resins by lignin is therefore an obvious research approach. This creates opportunities for partly bio-based adhesives for many applications, as phenolic resins are for example used to bond plywood, laminated veneer lumber (LVL), mineral wool, and more. Although many examples of lignin modified phenolic adhesives can be found in scientific literature, the implementation in industrial processes is very rare. One of the main reasons is not the quality of the adhesives as such, but the occurrence of technical difficulties upon upscaling from laboratory to industrial scale when working with powdered lignin. Typical problems comprise powder deposits due to static electricity, poor powder flow, blockages in pipes and/or filters, excessive dissolution times, and sedimentations. In order to overcome these difficulties, phenol/lignin blends were developed that allow the synthesis of lignophenolic resins for numerous applications on industrial scale. The suitability for these resins to be used to bond wood was demonstrated

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L. F. M. da Silva et al. (eds.), *3rd International Conference on Industrial Applications of Adhesives 2024*, Proceedings in Engineering Mechanics,
https://doi.org/10.1007/978-3-031-69503-2_1

with the examples plywood and laminated veneer lumber, whereas the suitability for usage as a technical resin was demonstrated on glass fibre.

Keywords Phenol-Lignin blend (PLB) · Lignophenolic resin (LPF) · Plywood · Laminated veneer lumber (LVL) · Mineral wool

1 Introduction

In recent decades, lignin obtained from wood has attracted considerable attention in science and industry. This is partly due to its availability and partly due to its versatile properties (Tribot et al. 2019). The structure and concentration of lignin vary depending on botanical origin, plant tissue, age and type of cell wall layer. Lignin is considered a structural substance of wood and woody plants. In softwood (e.g. pine) the lignin content is around 15–25% by weight and in hardwood (e.g. eucalyptus) around 27–33% by weight. Every year, around 150 billion tonnes of lignin are synthesised by plants on earth, making this biopolymer the second most abundant macromolecule group on earth after cellulose (Tribot et al. 2019). In total, lignin accounts for 30% of all non-fossil organic carbon on Earth (Hu et al. 2018).

However, lignin is mainly considered as a by-product from biorefineries of the second-generation (e.g. as organosolvlignin) or from the pulp and paper industry (as kraft lignin or lignosulfonate, depending on the process). Although lignin has great potential, it is often underutilised, for example through internal energy production by combustion (Souza et al. 2020, Bajwa et al. 2019, Tribot et al. 2019). This is disappointing as lignin is the major source of phenolic compounds on Earth. Furthermore, the use of lignin does not compete with the food industry, which is a common ethical issue with other renewable resources (Gomiero et al. 2010). There are several main reasons for burning lignin. On the one hand, lignin is a complex and heterogeneous material with different functional groups such as methoxy (CH3O), carboxyl (COOH) and carbonyl (C = O) groups (Huang et al. 2019). In addition, the structure changes depending on the origin, season and growing conditions, making it difficult to know or reproduce the exact composition and structure. On the other hand, the phenolic structure is chemically very stable and difficult to transform and change.

As a biopolymer composed of phenolic building blocks, the structural composition of lignin is similar to that of synthetically produced phenol–formaldehyde (PF) resins (Gong et al. 2022). PF adhesives are usually synthesised using fossil-based phenol, formaldehyde and alkaline catalysts. Growing socio-environmental and economic concerns about the scarcity of fossil resources have fuelled the search for substitutes for petroleum.

The amount of substitutable synthetic adhesive with sustainable lignin is determined by the product quality requirements, especially the strength achieved, and by the commercial production conditions, which require sufficient reactivity and processability of the binder. Solt et al. (2019) substituted 50 wt% phenol with pine kraft lignin and found large differences in terms of reactivity and resin performance.