High porosity cellulose nanopapers as reinforcement in multi-layer epoxy laminates

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Abstract
Utilizing high-performance cellulose nanopapers as 2D-reinforcement for polymers allows for realizing high-loading fraction (80 vol.%), high-performance (strength >150 MPa, modulus >10 GPa) laminated nanopaper reinforced epoxy composites. Such cellulose nanopapers are inherently dense, which renders them difficult to be impregnated with the epoxy-resin. High-porosity nanopapers facilitate better resin impregnation, truly utilizing the properties of single cellulose nanofibres instead of the nanofibril network. We report the use of high-porosity (74%) but low strength and modulus bacterial cellulose (BC) nanopapers, prepared from BC in ethanol dispersion, as reinforcement for epoxy-resin. High-porosity nanopapers allowed for full impregnation of the BC-nanopapers with epoxy-resin. The resulting BC-reinforced epoxy laminates possessed high tensile modulus (3 GPa) and strength (100 MPa) at a BC loading of 30 vol.-%, resulting from very low void-fraction (3 vol.-%) of these papergs compared to conventional nanopaper-laminates (10+ vol.-%). Better resin impregnation of less dense nanopapercelullose networks allowed for maximum utilization of stiffness/strength of cellulose nanofibrils.

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1. **Vacuum infusion of cellulose nanofibre network composites: Influence of porosity on permeability and impregnation**
   By: Aitomaki, Yvonne; Moreno-Rodriguez, Sergio; Lundstrom, T. Staffan; et al.
   MATERIALS & DESIGN Volume: 95 Pages: 204-211 Published: APR 2016
   Times Cited: 14

2. **Reinforcing efficiency of nanocellulose in polymers**
   By: Aitomaki, Yvonne; Oksman, Kristiina
   REACTIVE & FUNCTIONAL POLYMERS Volume: 85 Special Issue: SI Pages: 151-156 Published: DEC 2014
   Times Cited: 32

3. **Hierarchical wood cellulose fiber/epoxy bio composites - Materials design of fiber porosity and nanostructure**
   By: Ansari, Farhan; Skjoldt, Anna; Larsen, Per Tomas; et al.
   COMPOSITES PART A APPLIED SCIENCE AND MANUFACTURING Volume: 74 Pages: 60-68 Published: JUL 2015
   Times Cited: 23

4. **Cellulose nanofiber network for moisture stable, strong and ductile biocomposites and increased epoxy curing rate**
   By: Ansari, Farhan; Galland, Sylvain; Jehansson, Mats; et al.
   COMPOSITES PART A APPLIED SCIENCE AND MANUFACTURING Volume: 63 Pages: 35-44 Published: AUG 2014
   Times Cited: 72

5. **Interface tailoring through covalent hydroxyl-epoxy bonds improves hygromechanical stability in nanocellulose materials**
   By: Ansari, Farhan; Lindh, Erik L.; Furo, Istvan; et al.
   COMPOSITES SCIENCE AND TECHNOLOGY Volume: 134 Pages: 1753-183 Published: OCT 2016
   Times Cited: 10

6. **Nanostructured biocomposites based on unsaturated polyester resin and a cellulose nanofiber network**
   By: Ansari, Farhan; Skjoldt, Mikael; Berglund, Lars
   COMPOSITES SCIENCE AND TECHNOLOGY Volume: 117 Pages: 289-306 Published: SEP 2015
   Times Cited: 47

7. **Title: [not available]**
   By: BROWN AJ
   J CHEM SOC T Volume: 49 Pages: 172 Published: 1886
   Times Cited: 97

8. **Mapping tree density at a global scale**
   By: Crowther, T.W.; Glick, H.B.; Covey, K.R.; et al.
   NATURE Volume: 525 Issue: 7568 Pages: 201-4 Published: SEP 2015
   Times Cited: 217

9. **Structural investigations of microbial cellulose produced in stationary and agitated culture**
   By: Czaja, W; Romanowicz, D; Brown, RM
   CELLULOSE Volume: 11 Issue: 3 Pages: 403-411 Published: SEP 2004
   Times Cited: 300