Microstructure and nanomechanical property of coupling agent treated WPC

Yonghui Zhou and Mizi Fan*

Department of Mechanical, Aerospace and Civil Engineering, College of Engineering, Design and Physical Sciences, Brunel University London, Uxbridge, UB8 3PH, UK

*mizi.fan@brunel.ac.uk

Introduction

Wood plastic composites (WPC) have been consistently growing in the last decade for uses in many industrial sectors, such as decking, automotive, siding, fencing and outdoor furniture. Due to the inherently highly polar and hydrophilic nature of wood flour or fibre which makes it incompatible with hydrophobic and non-polar matrices, various modifications including both physical and chemical approaches have been attempted in order to formulate decent WPC with optimum interface bonding.

The focus of this paper was to optimise the interface of WPC by the use of silane and maleated coupling agents, hence to reveal the variations of the microstructure of the composites. Furthermore, the effect of the coupling agent treatments on the *in situ* mechanical properties of the composites were first determined by conducting nanoindentation analysis, which led to a better understanding of interfacial characteristics.

Materials and Methods

Recycled wood flour and polyethylene (PE) were supplied by Rettenmeier Holding AG (Germany) and JFC Plastics Ltd (UK) respectively. Coupling agents (Fig. 1) including maleated polyethylene (MAPE), bis(triethoxysilylpropyl)tetrasulfide (Si69) and vinyltrimethoxysilane (VTMS) were purchased from Sigma-Aldrich UK. A Brabender Plastograph twin-screw mixer was used for the compounding of the materials and the formulation method was compression moulding. Both the untreated and treated composites were transversely cut by using a sliding microtome with the nominal thickness of around 25 microns for the microstructure investigation of the cross sections on Fluorescence Microscope (FM) and Scanning Electron Microscope (SEM). Nanoindentation tests (Fig. 2) were performed on a Nano Indenter (Hysitron TI 950 TriboIndenter, USA) equipped with a three-side pyramid diamond indenter tip.

Fig. 1 Chemical formulae of the coupling agents

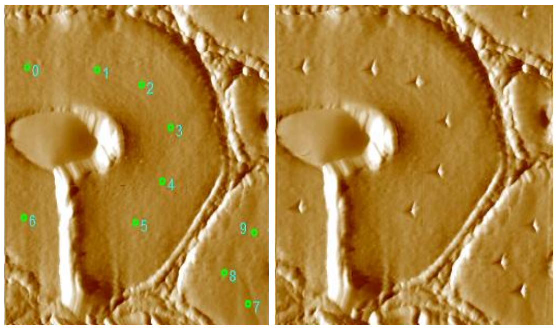

Fig. 2. Typical *in situ* imaging nanoindentation test

Results and Discussion

The effect of the coupling agent treatment on the interface bonding scenarios of the composites was scrutinised by the use of FM and SEM (Fig. 3 and Fig. 4).

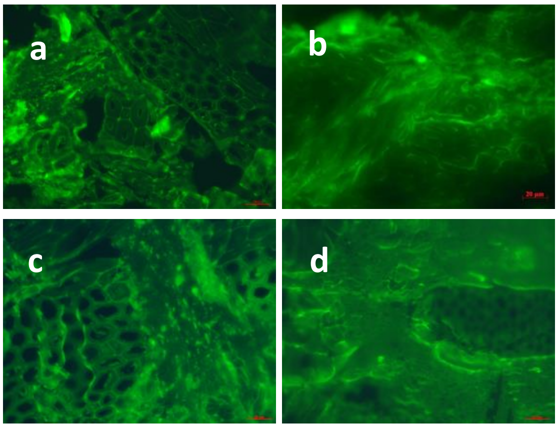

Fig. 3 FM photographs of cross section of untreated (a), MAPE treated (b), Si69 treated (c) and VTMS treated (d) composites.

It can be seen a number of clear cracks or boundaries and voids between wood particles and the matrix occurred in the untreated WPC, which indicated a poor compatibility between the untreated raw materials. It was also observed that there were agglomerated wood particles unevenly distributed in the matrix. In addition, although there were a few cell lumens partially filled by the polymer resin, the majorly unfilled cell lumens along with the existence of micro cracks between wood and PE denoted its improper interfacial adhesion.

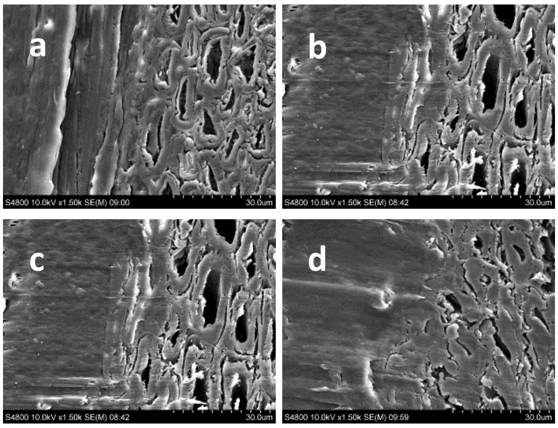

Fig. 4 SEM photographs of cross section of untreated (a), MAPE treated (b), Si69 treated (c) and VTMS treated (d) composites.

Comparatively, in the treated WPC (Fig. 3b-3d and Fig 4b-4d), wood flour was completely wetted by the matrix and firmly bonded to it, demonstrating superior interfacial adhesion with resin impregnation throughout the interface. More importantly, a large number of cell lumens of these samples were discerned to be partially or utterly filled by the resin. It was interesting that apart from the cell lumens, the vessels of the wood particles in the treated samples (especially VTMS treated) were also completely or partially impregnated with PE polymer (Fig. 4d).

The examination of the mechanical properties at nanoscale would undeniably help reveal the interface characteristics and evaluate the overall property of the composites. Fig. 5 demonstrated the nanomechanical properties of the wood cell walls of the composites determined by nanoindentation.

The untreated composite showed an elastic modulus of 16.42 GPa and a hardness of 0.53 GPa, while the counterparts of the MAPE and Si69 treated composites interestingly decreased to 11.46 GPa and 0.46 GPa (MAPE), and 15.60 GPa and 0.49 GPa (Si69) respectively. The drops of the modulus and hardness were assumed to be partially resulted from the fibre weakening or softening impact of the treatments, namely the chain scission and weakening of interfibrillar interaction in cellulose occurred with the presence of maleic and silane coupling agents under high pressure and temperature during processing. On the other hand, it might be associated with the crystalline structure transformation of wood flour.

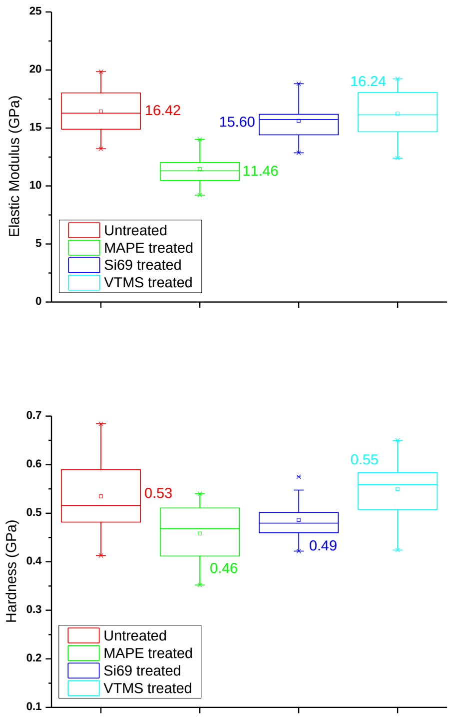

Fig. 5 Nanomechanical property of the composites by nanoindentation

More importantly, the better nanaomechanical property of VTMS treated composite over MAPE and Si69 treated composites should be ascribed to the severe deformation and damaging of its cell walls, giving rise to a higher level of penetration, which was assumed to compensate the loss of the *in situ* mechanical properties due to the aforementioned fibre weakening or softening impact and crystalline transformation.

Conclusions

SEM observation revealed that the coupling agent treatments enhanced the interfacial compatibility and adhesion of WPC, while the *in situ* mechanical properties were not primarily governed by the interfacial adhesion.

Acknowledgements

The author gratefully acknowledge the funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement number 690323 (SMART-Plant).