How surface tension and adhesive force measurements can help to improve the mechanical properties of basalt fibers

Basalt fibers (BF) have attracted great attention due to their cost-efficiency, high tensile strength, high resistance to environmental effects and its environmentally friendly characteristics. Unfortunately, the manufacturing of BF is challenging leading to fibers with defects like scratches, crystals and voids lowering the strength of the material. The use of coupling agents, antistatic and lubricant agents and sizing can prevent the problems caused by defects to some extent. The sizing is a thin, homogenous coating applied to the fiber surface during the manufacturing process to protect the filaments. Previous studies from Ma's group showed that sizing plays a key role in enhancing the mechanical strength of BF. However, due to the secrecy in the manufacturing process and the complexity of sizing formulations, sizing effects on BF are still not clearly understood. Recently, Ma's group has further investigated the effect of constituents in the sizing on mechanical properties of BF and demonstrated the correlation between the wettability of the sizing layer and enhancement of mechanical properties.

In this work, the authors searched for an optimal sizing for BF by applying the Taguchi method. The experiments were designed according to the Taguchi orthogonal array design (**Table 1**) revealing that the addition of sizing significantly enhances the tensile strength of both bundles and single fibers.

Table 1. *Experiments based on a Taguchi orthogonal array design*

Parameters	Experimental level		
	1	2	3
A: Main film former (epoxy) concentration (wt%)	2.0	4.0	6.0
B: Auxiliary film former (PU) concentration (wt%)	1.0	2.0	3.0
C: Coupling agent concentration (wt%)	0.5	0.8	0.3

They could furthermore confirm that the main film former (epoxy) plays the most important role in improving the strength, followed by the auxiliary film former (PU) and the coupling agent (KH-550).

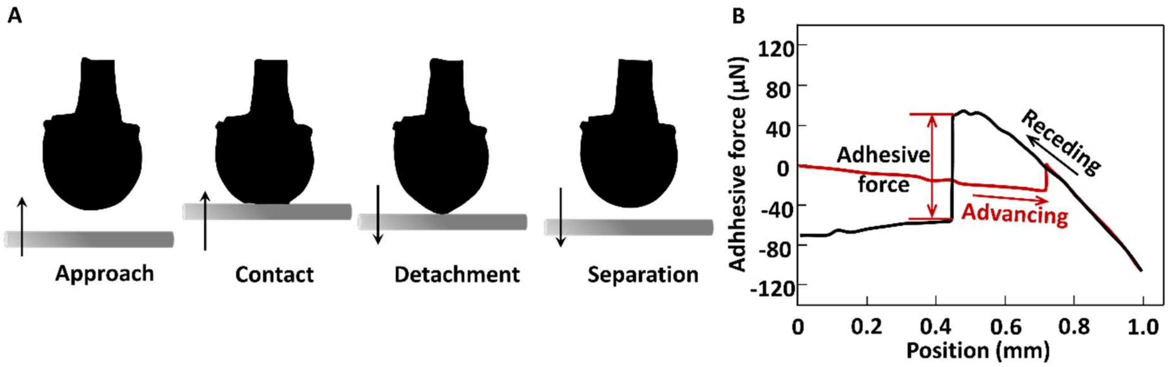
Also, the wettability is essential for a high performance of sizings. Usually, sizings with good wettability show a better spreading and coverage on the fiber surface. Both the surface tension and the adhesive force are vital parameters for determining the sizing performance, being indicators for the wettability of a fiber surface. The surface tension of the sizing formulation and the adhesive forces between the fiber and different sizing formulations were measured (**Table 2 and Picture 1**).

The data shows that a higher surface tension is always accompanied by a lower adhesive force, because a higher surface tension leads to a lowered wettability between the sizing and BF. For instance, Sample No.2 had the highest surface tension but lowest adhesive force. In addition, the treatment of sizing would increase the tensile strength of both bundles and single fibers. The sizings with lower surface tension and thus a better wettability between the sizing and BF showed a higher mechanical strength of the BF. The addition of sizing effectively enhances the interactions among the individual fibers reducing the stress concentration at the surface defects, providing a healing function to the surface defects on the fiber surface. By just measuring the surface tension of the sizing, firm a conclusion for the mechanical strength of the BF can be drawn. **Table 2** provides a basic guideline for optimizing the sizing for BF.

Table 2. *Properties of different sizing samples and corresponding bundle and single fibers*

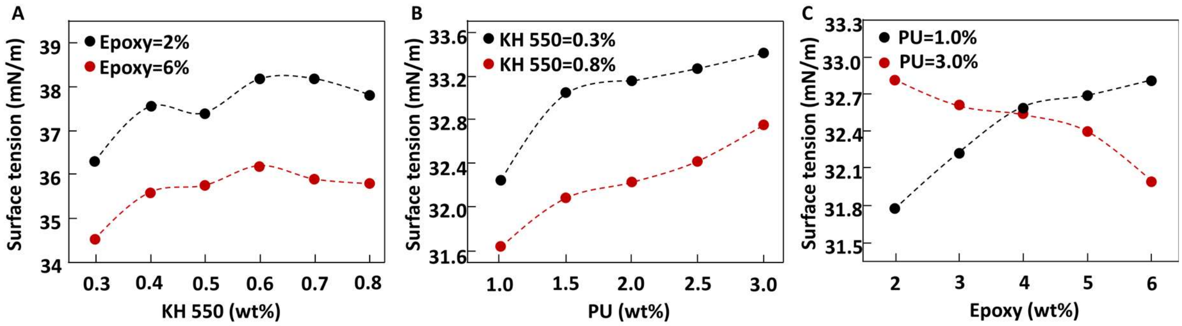
Sample No.	Experimental scheme	Surface tension (mN/m)	Adhesive force with BF (µN)
1	$A_1B_1C_1$	26.02	109.08
2	$A_1B_2C_2$	27.15	104.84
3	$A_1B_3C_3$	26.71	110.32
4	$A_2B_2C_3$	25.73	122.37
5	$A_2B_3C_1$	24.76	128.22
6	$A_2B_1C_2$	24.31	130.19
7	$A_3B_3C_2$	23.61	171.48
8	$A_3B_1C_3$	23.79	138.99
9	$A_3B_2C_1$	24.43	129.23
BF without sizing		55.45	/

Moreover, the authors successfully determined the optimal parameters of sizing ($A_3B_1C_2$) for BF based on the signal-to-noise (S/N) ratio of Taguchi method and ANOVA analysis, and the predicted results showed good consistency with the experimental results.



Picture 1. *(A) Approach, contact, detachment, and separation of a sizing droplet on BF; (B) Force-displacement curve of sizing droplet interaction with the single fiber*

To better understand the possible interaction among various components in the sizing, they measured the surface tension of the sizing formulations. **Picture 2** demonstrates that the effect of KH-550 on the surface tension was irrelevant with epoxy concentration; likewise, the effect of PU on the surface tension had no relation with KH-550 concentration. However, a strong interaction existed between epoxy and PU due to the reaction between the epoxide and amide groups. Therefore, the interaction among various components in sizing should also be considered while designing the formulation.



Picture 2. *Surface tension of sizing components of epoxy and KH 550 (A), KH 550 and PU (B), PU and epoxy (C).*

In summary, this work enhanced the understanding for sizing effects on the mechanical properties of BF. Sizing efficiently helps to improve the mechanical properties of BF due to its healing function to defects on the fiber surface. Surface tension and adhesive force measurements confirmed that a good wettability of sizing to BF plays an important role in enhancing the performance of BF. Furthermore, surface tension is an essential parameter for developing the sizing formula for BF considering the interactions among the constituents, and the compatibility between fiber and sizing. This work sheds light on a unique technique of designing sizing formulations for BF utilizing the Taguchi method.

A dynamic contact angle measuring devices and tensiometer DCAT (DataPhysics Instruments GmbH, Germany) was used in this research.

For more information, please refer to the following article:

Optimization on the formulation of sizing to enhance the mechanical properties of basalt fiber; Dan Xing, Xiong-Yu Xi, Ming-Gang Qi, Qing-Bin Zheng, Peng-Cheng Ma, *The Journal of The Textile Institute* ***2020***; DOI: 10.1080/00405000.2020.1771078