independent of increasing environmental temperatures from 20℃ to 220℃. The load-displacement curves are almost the same for specimens with environmental temperature from 20℃ to 70℃. Thus, it is reasonable to conclude that the compressive performances of bamboo structural elements are stable for normal service temperature conditions. The ultimate compressive capacity of EB increase obviously when the environmental temperatures are 100℃, 130℃, and 160℃. For compressive specimens with heating environment temperatures higher than 100℃, The plastic plateau noticed for specimens under 100℃ is disappear along with the brittle failure modes are noticed, as shown in Fig. 3. The compressive strength for unidirectional laminated engineered bamboo boards is decreased to 0.7 times of the reference strength values when the heating environmental temperature is 220℃. For multidirectional laminated bamboo boards, increasing strength values are noticed for 120 mm height specimens, whereas it is decreased to 0.8 times of the reference strength values, under 220℃ heating temperature for 1.5 hours. More researches are required to understand the mechanism behind it.

The load-displacement curves of unidirectional laminated bamboo boards, under three different heating conditions with the same heating temperature, are given in Fig. 4(g). Three groups of specimens, cataloged as during the heating, shortly after the 1.5 hours heating and conditioned 48 hours after the heating, are tested. It is interesting to notice that the compressive behaviors are changed dramatically after the heating event. It is revealed that the mechanical properties of bamboo are changed during a fire event, and more researches are required for a deep understanding of this phenomenon, which is necessary for the safety management strategy design of bamboo structures under fire event.

3.3 parametric analysis

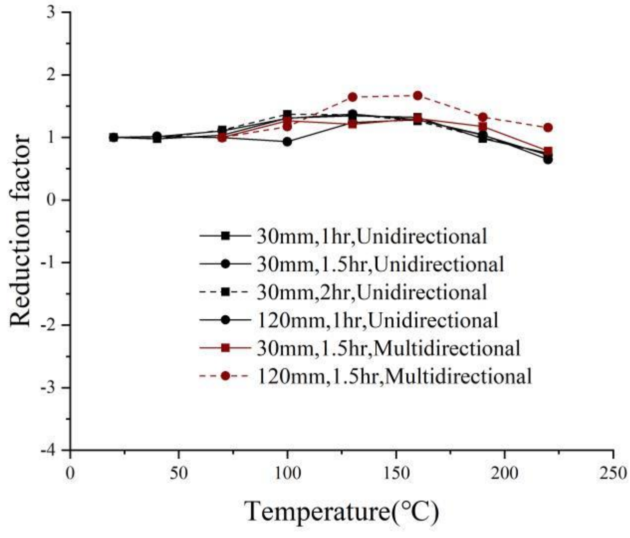

Fig. 5 Strength reduction factor of bamboo with different heating conditions

As shown in Fig. 5, based on the original test data, the influence of various parameters on the high-temperature performances of bamboo materials are studied in this research. Two types of engineered bamboo boards show similar high-temperature performance with increasing heating temperature. For 120 mm height specimens under 190℃ heating for 1.5 hours, the multidirectional laminated bamboo specimens show an increasing bearing capacity, whereas the unidirectional laminated bamboo specimens show a decreasing bearing capacity. In other words, the multidirectional laminated bamboo shows a higher high-temperature resistance capacity in this research. Three different heating periods are used in this research; however, small differences in the compressive behaviors are noticed for the specimens with different heating hours, as shown in Fig. 5. Thus, the 1.5 hours heating period is suggested for future researches, which is more than the fire resistance time (1 hour) required for timber structures in China (GB 50016 2014).

The 30 mm height is suggested by the ISO (ISO 13061 2017) and Chinese stand (GB/T 1935 2009) for wood materials with the consideration of so-called clear wood specimens to exclude the influence of wood knots. The 120 mm height is given by ASTM standard (ASTM D143 2014), and it is adopted by the previous studies on the mechanical properties of engineered bamboo products (Li 2020). As shown in Fig. 3, the changes in failure modes can be distinguished easily with relatively taller sample height. The height of specimens has little influence on the high-temperature resistance performances of unidirectional bamboo boards. For multidirectional laminated boards, it seems that the 120 mm height specimens have a slightly better high-temperature resistance ability than 30 mm height ones. Many pieces of research indicate the prefabricated patterns have an apparent influence on the thermal performance of composite materials (Gibson 2016). However, a similar mechanism for biocomposite materials, such as bamboo, is still not clear up to now.

4. CONCLUSION

The compressive performances of two types of engineered bamboo panes shortly after a heating environment were experimentally studied in this research. Strength degradation is noticed for specimens with a heating temperature of more than 100℃. The compressive test of specimens under three different conditions, cataloged as during the heating, shortly after the heating and conditioned 48 hours after the heating, indicating that the mechanical properties of bamboo material would change obviously after a fire event. More researches are required for a reasonable understanding of this phenomenon. Parametric analysis of various parameters, including the type of bamboo boards, heating time, and size of specimens, are analyzed in this research.

The test results reported in this research can be used as a reference for the fire resistance performance of engineered bamboo structures. Meanwhile, the specimen size of $t \times t \times 120$ mm, with t is the thickness of bamboo boards, and 1.5 hours heating period is recommended for future studies on the high-temperature performance of engineered bamboo products.

REFERENCES

ASTM D143 (2014), "Standard test methods for small clear specimens of timber", ASTM International, West Conshohocken, United States.

GB 50016 (2014), "Code for fire protection design of buildings", China Planning Press, Beijing, China.

GB/T 1935 (2009), "Method of testing in compressive strength parallel to grain of wood", Standards Press of China, Beijing, China.

Gibson R. F. (2016), "Principles of composite material mechanics," Taylor & Francis Inc., Portland, United States.

ISO 13061 (2017), "Physical and mechanical properties of wood – Test methods for small clear wood specimens –Part 17: Determination of ultimate stress in compression parallel to grain", ISO, Switzerland.

Li, Z., He, X. Z., Cai, Z. M., et al. (2020), "Mechanical properties of engineered bamboo boards for glubam structures," *J. Mat. Civil Eng.*, ASCE. (Accepted)

Li, Z., Yang, G. S., Zhou, Q., et al. (2019), "Bending performance of glubam beams made with different processes", *Advances in Structural Engineering*, **22**(2), 535-546.

Wang, R., Xiao, Y. and Li, Z. (2017), "Lateral loading performance of lightweight glubam shear walls", *J. Struct. Eng.*, ASCE, **143**(6), 04017020.

Wu, Y. and Xiao Y. (2018), "Steel and glubam hybrid space truss", *Engineering Structures*, **171**, 140-153.

Xiao, Y., Chen, G. and Feng, L. (2014a), "Experimental studies on roof trusses made of glubam", *Materials and Structures*, **47**, 1879-1890.

Xiao, Y., Li, L. and Yang, R. Z. (2014b), "Long-term loading behavior of a full-scale gubam bridge model", *J. Bridge Eng.*, ASCE, **19**(9), 04014027.

Xiao, Y. and Ma, J. (2012), "Fire simulation test and analysis of laminated bamboo frame building", *Construction and Building Materials*, **34**, 257-266.

Xiao, Y. and Shan, B. (2013), "Glubam structures", China Architecture & Building Press, Beijing, China.

Xiao, Y., Zhou, Q. and Shan, B. (2010), "Design and construction of modern bamboo bridges", *J. Bridge Eng.*, ASCE, **15**(5), 533-541.