Effect of Loading Direction and Temperature on Compressive Behavior of Compressed Laminated Wood in LNG/LPG Tank Supporter

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Abstract: The objective of this study was to investigate the fracture characteristics and compressive strengths of compressed laminated wood (CLW) according to loading directions. The results for compressive strength in the CLW tended to be constant regardless of the number of laminae. It appears that there is no size effect under compressive load, and the CLW had the different strength values and the fracture characteristics according to the loading direction and temperature. In particular, the fracture behavior of the CLW in room temperature and cryogenic tests was such that it exhibited a burst phenomenon under the compressive load in the parallel direction relative to stacking direction. It was identified that the fracture characteristic for the burst phenomenon is associated with shear fracture in the laminated composite material.

Key-Words: Compressed laminated wood, compressive test, fracture behavior, burst phenomenon, cryogenic test, LNG storage tank support

1 Introduction

The heavy industries for the shipbuilding are make much effort to develop different types of LNG and LPG carriers by rising demands for liquefied natural gas (LNG) and liquefied petroleum gas (LPG). These carriers vary in their storage method or the insulation system applied to the LNG and LPG storage tanks. Therefore, it is important to determine the type of storage method and the insulation system in the LNG and LPG carrier design. In particular, the construction of the LNG or LPG storage tank can be subdivided into two major sections, such as the internal and external structures. In the internal structure of the storage tank, the determination for the insulation system is an important factor to prevent heat transfer, and the compressive strength need to support the tank should be considered as well as heat transfer in the external structure. Currently, in order to satisfy these requirements, the compressed laminated wood (CLW) is being widely applied to the support of LNG and LPG storage tank.

To investigate their exact characteristics for mechanical properties and fracture mechanisms, many studies have been conducted in the past few years. Especially some studies for uniaxial compression test in the wood have been conducted to investigate the material characteristics according to loading direction [1-3]. In addition, Burdurlu et al. [4] examined the effects of the configuration of ply on the bending strength and modulus of elasticity in beech and poplar wood. Anshari et al. [5] investigated the effects of moisture-dependent swelling on compressed wood, and they examined the ultimate failure modes of pre-stressed short and long glued laminated timber beams. Osmannezhad et al. [6] examined the effects of using GFRP layers between layers of glulam and compared the results of a three-point loading test with those obtained with both unreinforced and reinforced glulam. Moreover, the effect for non-reinforced glulam and solid beams were investigated in beech and poplar. Nadir and Nagarajan [7] conducted tests to determine the flexure of horizontally glued laminated rubber wood and compared the properties with those of a solid beam. Subsequently, the effects of the laminae thickness and laminae interfaces were investigated. In addition, Deng et al. [8] investigated the failure mechanism under compressive loads.

However, there are no the fracture mechanism for the burst phenomenon under compressive loads. The CLW has the fracture mechanism for the burst phenomenon and kinking phenomenon according to loading direction. In addition, this CLW can be used for one or two years in field due to the fracture by the weight of the tank and variations in temperature. Therefore, it is necessary to conduct studies to accurately evaluate the mechanical properties of the material and predict the fractures. The objective of this study was to examine the properties of the CLW and establish an initial database in order to improve the performance of the CLW.

2 Experiment details

To investigate the behavior of the CLW under compression load, experiment specimens composed of German beech were prepared. The density of the specimens was 1350 kg/m3. The compressive strength of the CLW may vary because the number of laminae depends on the dimension of the specimen. Therefore, in order to examine the effect for the specimen dimension, the specimens reinforced with phenol formaldehyde resin were produced in 10 mm x 10 mm, 15 mm x 15 mm, 20 mm x 20 mm, 25 mm x 25 mm (width x length x thickness), as shown in Table 1.

Fig. 1 shows the schematic diagram for a universal testing machine and the compressive load directions that were subdivided into the perpendicular and parallel directions relative to the stacking directions. For the test, the universal testing machine (UH1000KNI, Shimadzu) was adopted, while the test speed was adjusted to 0.1L mm/min as specified in ISO 604 [9].

Table 1 Compression test scenario for compressed laminated wood

Speci-men	CLW sample size (*in mm*)			Nu-mber of lami-nae	Compr-essive load direction relative to stacking direction
	Wid-th (*W*)	Len-gth (*L*)	Thic-kness (*T*)	(*N*)	
RT-1	10	10	10	7	Parallel
RP-1	10	10	10	7	Perpend-icular
RT-2	15	15	15	11	Parallel
RP-2	15	15	15	11	Perpend-icular
RT-3	20	20	20	15	Parallel
RP-3	20	20	20	15	Perpend-icular
RT-4	25	25	25	17	Parallel
RP-4	25	25	25	17	Perpend-icular

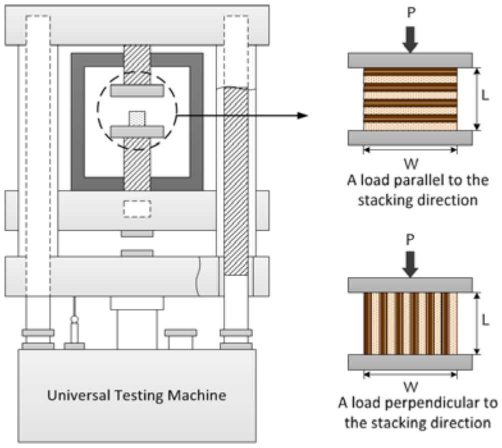
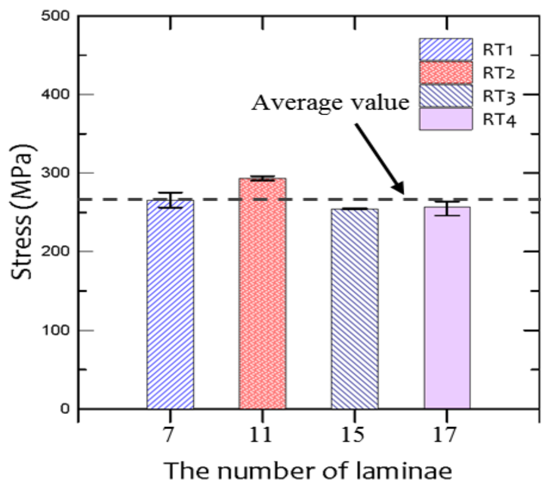
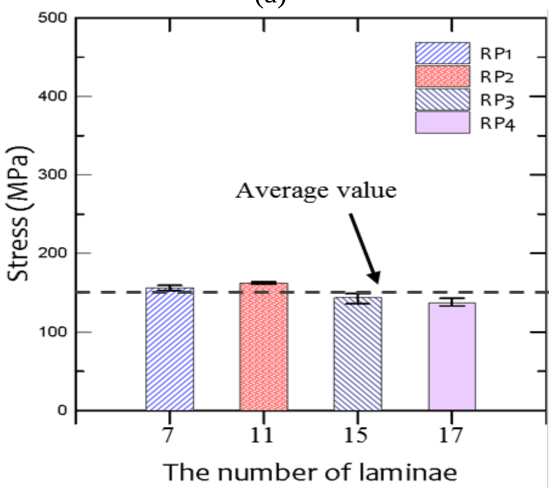


Fig. 1 Schematic diagram of the universal testing machine and compressive load directions

3 Experiment results



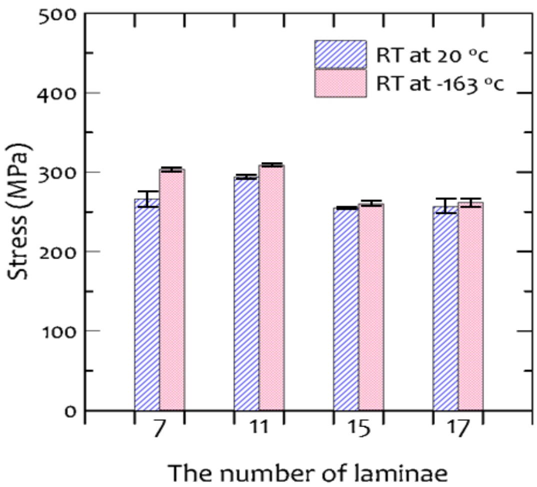
(a)



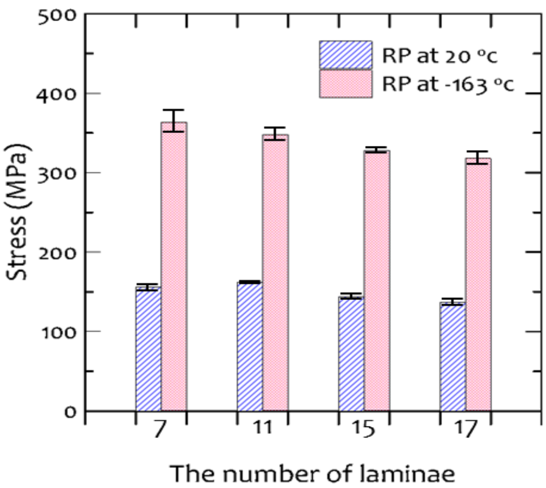
(b)

Fig. 2 Compressive strength of samples under compressive loads in (a) parallel and (b) perpendicular directions relative to stacking direction

Fig. 2 shows the stress measurements obtained for the CLW samples under compressive load in perpendicular and parallel directions relative to stacking direction. It appears that there is no the effect for the dimension of specimen. However, the RT-2 samples had a compressive strength value of 294 MPa that is 9.8% higher than the average value for RT samples. This may have been due to the irregular material properties of the CLW that was brittle material. In addition, in the results for the RP samples, there were also no significant differences. They had an average compressive strength value of 148 MPa that is 55.5% lower than the average value for the RT samples.



(a)



(b)

Fig. 3 Compressive strength of samples according to the temperature under compressive loads in (a) parallel and (b) perpendicular directions relative to stacking direction

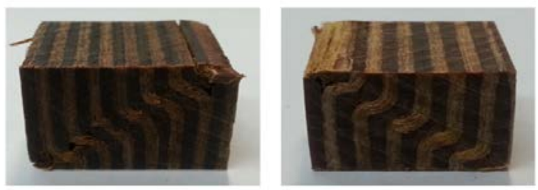
The given bar graph compares the compressive strength by the CLW samples on two different types of temperatures in the megapascal scale over the number of laminae from 7 to 17, as shown in Fig. 3. The data on RT samples in cryogenic test experienced a relatively small rise from around 5 to 30 MPa in comparison with the RT samples at room temperature. However, in the results for RP samples, there were significant differences from about 150 MPa to 180 MPa. This may have been due to the increase for the strength of the adhesion by the moisture and the matrix that covers the whole CLW.

Regarding the fracture behavior, the burst phenomenon, delamination phenomenon, and kinking phenomenon were observed, as shown in Fig. 4 and 5. The CLW samples under the compressive load in the parallel direction relative to stacking direction presented the burst phenomenon at room and cryogenic temperature. In addition, in the CLW samples under compressive load in the perpendicular direction relative to stacking direction, it was observed that the failure of the samples corresponded to the geometrical characteristics of the kink bands and the delamination phenomena.

(a)

(b)

Fig. 4 Fracture characteristics for the RT samples in the (a) room temperature and the (b) cryogenic tests



(a)

(b)

Fig. 5 Fracture characteristics for the RP samples in the (a) room temperature and the (b) cryogenic tests

4 Conclusion

In this study, compression tests were conducted on samples of compressed laminated wood, as used for the supports of LNG and LPG storage tanks. Compression tests according to the load directions relative to laminae orientation, dimensions and temperature were carried out. The results have the following general features.

- According to the compression test results, it can be seen that the CLW specimens had a high compressive strength.
- In addition, in cryogenic test, they tended to have the excellent compressive strength in comparison with the results at room temperature. In particular, it can be seen that there was the largest variation in the results of RP samples.
- Among the results obtained for the strength of the CLW, they can be applied to the support of other structures as well as the LNG storage tank under the room temperature and cryogenic environment.
- Moreover, in this study, the two fracture characteristics have been investigated from the macroscopic failure investigation.
- Theses fracture characteristics could be divided into two mechanisms, such as the burst phenomenon and kinking phenomenon.

Therefore, the results obtained in this study are expected to be applied to the LNG and LPG storage tank design, and enhance further understanding the structural behavior for the compressed laminated wood.

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