단순화된 Mark III 방열판의 구조 강도 평가에 관한 연구

Structural Strength Assessment of Simplified Mark III CS Plate

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Abstract

LNG cargo containment system (CCS) has the primary function of ensuring adequate thermal insulation with keeping natural gas below its boiling point. From the viewpoint of structural design, this LNG CCS can be treated as a laminated composite structure showing complex structural responses under the sloshing load which can be defined as a violent behavior of the liquid contents in cargo tanks due to external forced motions. As LNG CCS type, Mark III containment system from TGZ is considered in this paper and then its structural strength assessment is performed based on a simple higher-order shear deformation theory and maximum stress, maximum strain, Tsai-Wu failure criteria developed for laminated composite plates. The assessment is performed to the initial failure of the Mark III CS plate by investigating failure locations and loads.

keywords : LNG CCS Panel, Laminated composite plate, Failure criteria, Structural strength

1. Introduction

Rapid expanding market for Liquefied Natural Gas (LNG) brings ship building industry a need to design and build bigger and safer LNG carrying vessels to improve the economy of transporting LNG cargo. Thus, for LNG vessels, it is one of critical design objectives to secure suitable LNG cargo containment system (CCS). Concerning LNG CCS variations there are two basic types namely independent B-type such as spherical Moss or SPB IHI and membrane type such as GTT No96, Mark III or CS1. Among them the membrane type, more specifically Mark III containment system is considered in this paper in order to perform the structural strength assessment. In this assessment, the simple higher-order shear deformation theory is employed to calculate through-thickness deformation of the Mark III CS panel, which is basically a laminated plated structure, in conjunction with maximum stress, maximum strain and Tsai-Wu failure criteria for composite materials. The structural strength is calculated to the initial failure of the Mark III CS plate; the failure loads are calculated and the failure locations are identified. The assessment procedure developed in this paper can be used for the design of the Mark III CS panel at the preliminary design stage as quick and economic results are useful, before detailed and complex numerical modeling based procedure is performed at the later design stages.

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2. Structural Strength Assessment Procedure

In case of the structural strength assessment of a laminated plate, the mechanical responses of each ply such as strains and stresses due to an external load are fundamental with their corresponding ultimate strength values to predict failure. Thus for a given external load, ply-by-ply strength analysis can be performed by comparing calculated ply stresses or strains with the corresponding ultimate strengths in the failure criteria. A simplified higher-order shear deformation theory for laminated anisotropic plates, which can take into account not only transverse shear strains but also parabolic variations of the transverse shear strains in through-thickness direction without shear correction factors, is employed in this procedure to calculate stress components [Reddy, 1984]. In case of failure criteria used in the procedure such as maximum stress, maximum strain and Tsai-Wu, they are expressed in polynomial equations, and with these, the initial failures are judged to have occurred when a value of unity is reached [Ochoa and Reddy, 1990]. General strength assessment procedure is shown in Figure 1. This initial failure based procedure is applied to the strength of a plate exemplified from the Mark III CS. It should be mentioned that, in operation, the LNG CCS plate faces with a dynamic sloshing load. However, a static load is increased gradually up to the initial failure of the plate as the procedure is intended for the preliminary design level.

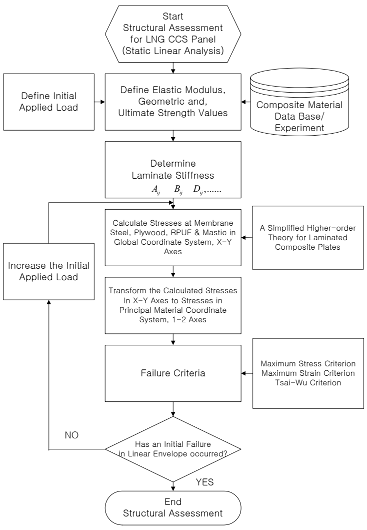

Fig. 1 Structural strength assessment procedure for the Mark III CS plate

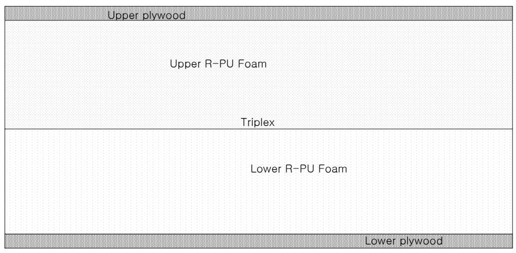

Fig. 2 An analytical model for simplified Mark III CS plate

3. Numerical Example and Concluding Remarks

Figure 2 shows a schematic drawing of simplified Mark III CS plate, which is a laminated composite structure composed of layers of fiber glass reinforced polyurethane foam, plywood and aluminium foil reinforced with glass cloth (called triplex). Please note that mastic and 304L stainless steel are ignored to focus on the primary and secondary barrier/insulation system of the Mark III CS. Table 1 shows the materials properties used in the strength procedure with thickness information for each layer. As it can be seen, ultimate strength values for triplex layer are absent due to their unavailability in public, and this affects the strength assessment of the simplified Mark III CS plate: when the stress components of the plate are calculated triplex layer is included in the analytical plate modelling, however this layer is not considered in the structural strength assessment procedure. The size of the plate taken from the Mark III CS is 1m in both long and short spans.

Table 1 Material properties used for plywood, triplex and RPUF

	Plywood		RPUF		Triplex	
	20^0C	-163^0C	20^0C	-163^0C	20^0C	-163^0C
E_{11}(GPa)	8.9	10.5	0.142	0.213	13.133	13.2496
E_{22}(GPa)	7.5	10.5	0.142	0.213	12.987	13.2496
G_{12}(GPa)	0.196	4.487	0.0122	0.0888	4.995	5.096
G_{13}(GPa)	0.196	0.196	0.0122	0.0621	4.995	5.096
G_{23}(GPa)	0.196	0.196	0.0122	0.0621	4.995	5.096
ν_{12}	0.17	0.17	0.24	0.2	0.3	0.3
ν_{21}	0.17	0.17	0.18	0.2	0.3	0.3
X_t(GPa)	0.04	0.06	0.0024	0.0024	-	-
X_c(GPa)	0.04	0.065	0.0024	0.0024	-	-
Y_t(GPa)	0.002	0.046	0.0014	0.0014	-	-
Y_c(GPa)	0.02	0.046	0.002	0.002	-	-
R(GPa)	0.0028	0.059	0.0014	0.0014	-	-
S(GPa)	0.0028	0.043	0.0014	0.0014	-	-
T(GPa)	0.0028	0.043	0.0014	0.0014	-	-
Thickness (mm)	10.0		135.0		0.7	

Results are shown in figures 3 and 4. In figure 3, the stress distributions of the exemplified plate are drawn for two cases: i) the plate under 20^0C operating temperature and ii) the plate under $20^0C/-163^0C$ operating temperature. For the latter case, it is assumed that the primary barrier/insulation system is subjected to 20^0C and the secondary barrier/insulation system including triplex layer are subjected to -163^0C. Effect of considering different operating temperature in the analytical plate modelling is clearly shown by observing τ_{xy}, τ_{xz} and τ_{yz} distributions. 15-bar on top of the plate is used as an applied load for the calculation of the stress components. Figure 4 shows the results of the initial failure loads of the plate. All the three different failure criteria locate the initial failure at the outmost plywood layer. Modelling uncertainty due to the use of different failure criteria is observed; maximum stress failure criterion calculated the lowest initial failure load while Tsai-Wu failure criterion calculated the highest initial failure load. Considering low operating temperature yields different initial failure loads, however, failure location is the same as previous case - the outmost plywood layer.

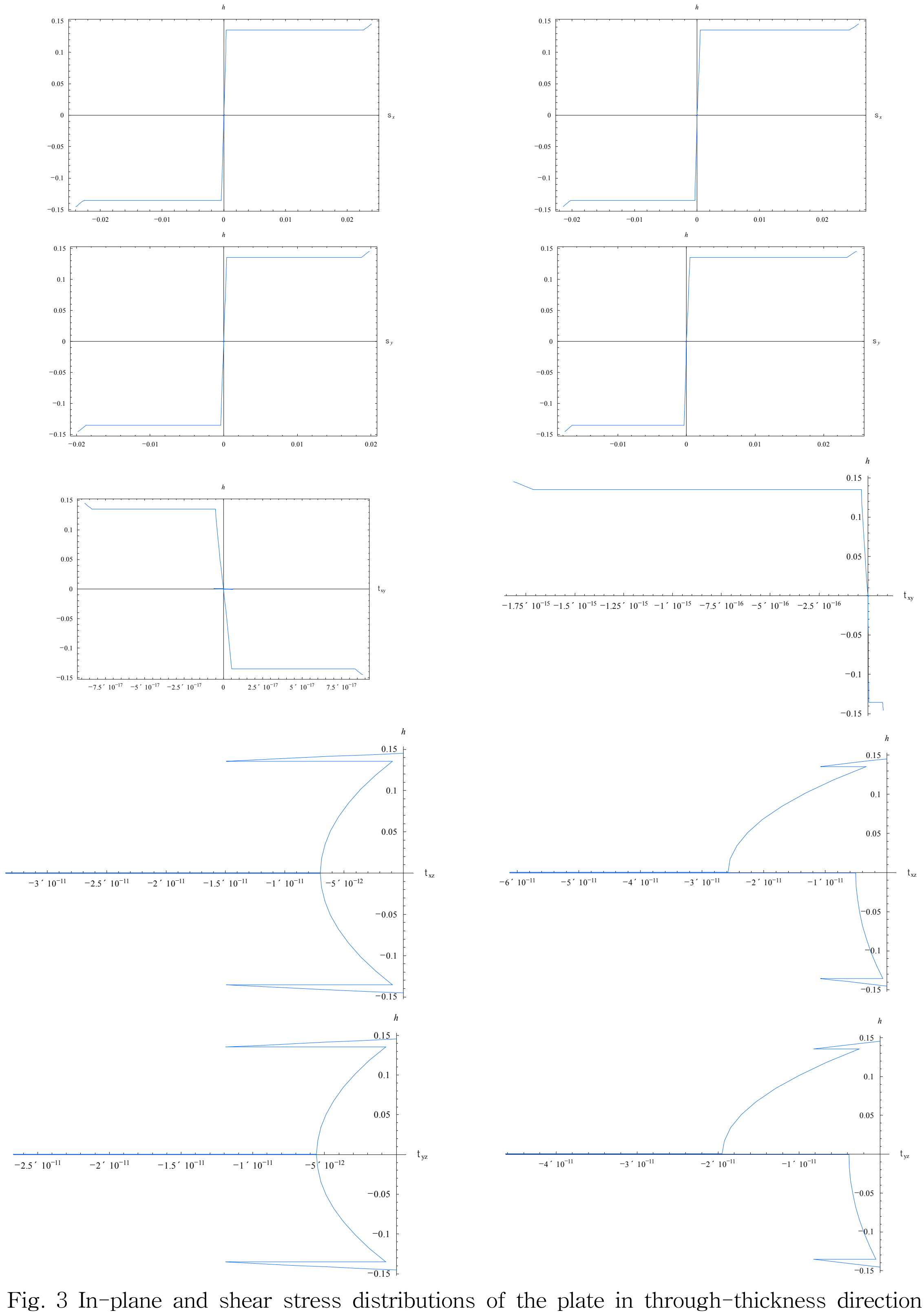

Fig. 3 In-plane and shear stress distributions of the plate in through-thickness direction (left: 20^0C, right: considering 20^0C and -163^0C)

From these results, one can conclude that the Mark III CS plate behaves stiffer in low temperature leading to a higher stress state and, subsequently, lower initial failure loads. It is expected that structural designers may seek the initial failure based design load information from the present strength assessment procedure.

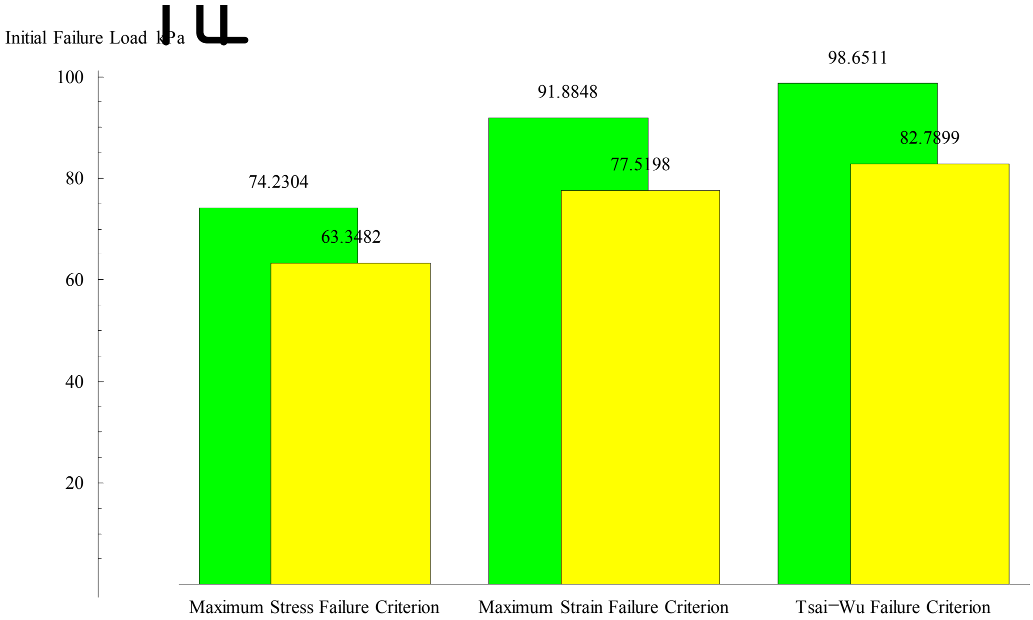

Fig. 4 Initial failure loads of the plate according to maximum stress/strain and Tsai-Wu failure criteria (green bars: 20^0C, yellow bars: considering 20^0C and -163^0C)

Acknowledgement

This research work was supported by Ministry of Knowledge and Economy, Korea through the Industrial Strategic Technology Development Program (Grant No. 10033791). The authors would like to thank their supports.

References

American Bureau of Shipping (2006) Guidance notes on “Strength Assessment of Membrane-type LNG Containment Systems under Sloshing Loads”.

Agarwal, B.D. and Broutman, L.J. (1990) Analysis and Performance of Fibre Composites, *John Wiley & Sons, Inc.*, second edition.

Det Norske Veritas (2006) Classification notes on “Sloshing Analysis of LNG Membrane Tanks”.

Ochoa, O.O. and Reddy, J.N. (1990) Finite Element Analysis of Composite Laminates, *Kluwer Academic Press*.

Reddy, J.N. (1984) A Simple Higher-order Theory for Laminated Composite Plates, *Journal of Applied Mechanics*, 51, pp.745-752.