Numerical analysis on dynamic responses of hybrid sandwich structures with V-type corrugated cores subjected to water impact

H. Wu, J. Liu, P. Zhang, M.H. He, Y.S. Cheng*

School of Naval Architecture and Ocean Engineering,

Huazhong University of Science and Technology, Wuhan, P.R. China

***Abstract*—In this paper, failure modes of hybrid sandwich structures (HSS) with V-type corrugated cores subjected to water impact are discussed. The dynamic responses and failure mechanism investigated using the LS_Dyna lagrange-Euler coupling techniques reveal that the face sheets undergo large stretching and bending deformation, while the core webs experience plastic bucking failure. The numerical simulation results are compared with the experimental data including a series of slamming pressures. The panels with the density of 31 kg/m^3 and 50kg/m^3 polyurethane foam filler have better performance in resisting to core webs plastic bucking failure compared to those without polyurethane foam filler under the same weight.**

Key words: Fluid-structure interaction, water impact, numerical simulation, hybrid sandwich structures

I. INTRODUCTION

Slamming (water impact) loads are important in the design of ships and offshore structure which can cause significant structural damage. Since the late-1920s,Von Karman[1] and Wagner[2] studied the water entry of a V-shape wedge of small dead rise angle. many research efforts have been devoted during the past century. In recent years, the Application of ULPMSS(Ultra-Light Porous metals sandwich structure) in Shipbuilding and offshore engineering drew wide attention[3-4]. Kaushik[5] investigates the hydrodynamic pressure of rigid and deformable hull bottom panels under slamming impact by commercial software LS_dyna. The pressure distributions are different with those obtained by using a plate theory and Wagner's slamming impact theory. Metskow and Janusz proposed[6-9] the concept of HSS(hybrid sandwich structures) which filled non metallic materials in ULPMSS, and conducted a series of fatigue tests for HSS. Burlayenko[10] researches the material elastic properties of aluminum honeycomb cores filled with polyvinyl chloride foams based homogeneous technique and stress predictions. Vyacheslav[11] studies the influence of polymeric foam on the free vibration and buckling characteristics for sandwich plates with a hexagonal honeycomb core. Zarei Mahmoudabadi[12] develops a theoretical model for the crushing behavior of the foam filled hexagonal honeycomb structure under quasi-static and low velocity impact loading. S.H. Yoo[13] investigates the performance of energy absorbers for foam-filled composite egg-box panels by compressive tests. The density of the foam filler have Influence on collapse response.

Hybrid sandwich structures with corrugated cores (HSS) are new type structures which may be used in high speed vessels. The mechanical properties of such new structures are rather different from those of the traditional stiffened plate structures. Therefore, the nonlinear dynamic responses and failure mechanism of HSS under slamming are key scientific problems to be solved.

In this paper, we investigate whether the V-type corrugated core sandwich panels filled with polyurethane foam have a better performance in water impact resistance compared to those without polyurethane foam filler under the same weight. Here, we employed commercial software LS_dyna to investigate the dynamic response of hybrid sandwich structures with V-type corrugated cores subjected to water impact. The numerical simulation results agree well with the experimental data.

II. MODELS OF NUMERICAL SIMULATION

Geometry Models. In this paper, all sandwich panels with a 780 mm×1000 mm exposure area to receive water impact consist of two equal thickness face sheets and corrugated core with a given web inclination angle of 60°. A sealed off round structure made by rigid materials (rigid out wall, see Fig. 1) is used to model clamped boundary condition. Hc=35mm. The calculated parameters for all 7 cases are

* Corresponding author. Tel.: 0086-27-87543258
E-mail address: yscheng@hust.edu.cn (Y.S. Cheng).

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shown in Table 1.

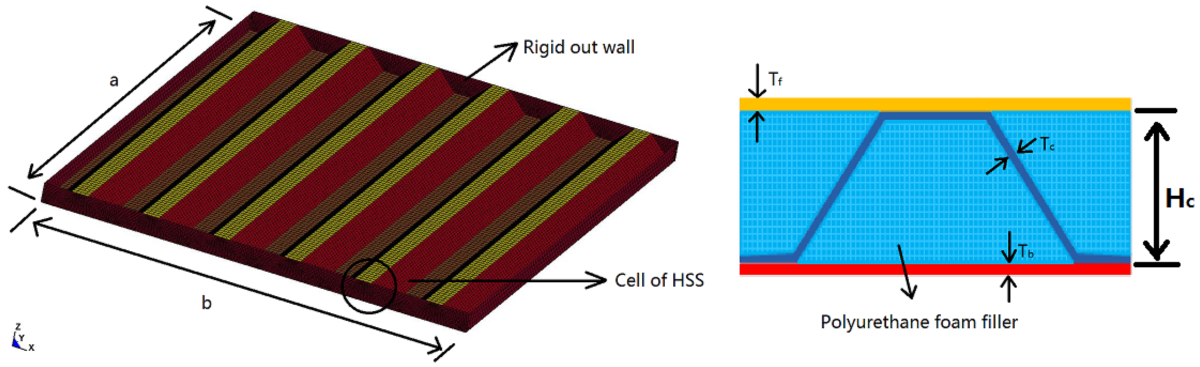

Fig.1 hybrid sandwich structures with V-type corrugated cores(HSS)

Table 1 Parameter values of calculation cases considered

No.	*Filler density Kg/m³*	*Tb mm*	*Tc mm*	*Tf mm*	Impact velocity m/s	*Weight kg*
1	/	1.1	0.45	1.1	7	17.12
2	/	1.1	0.54	1.1	7	17.85
3	31	1.1	0.45	1.1	7	17.94
4	50	1.1	0.45	1.1	7	18.48
5	/	0.45	1.4	0.45	7	10.32
6	31	0.45	1.4	0.45	7	11.14
7	50	0.45	1.4	0.45	7	11.68

Material Models. In the simulation, the mechanical behavior of both face sheets and core are modeled with Material Type 3 (*MAT_PLASTIC_KINEMATIC) in LS-DYNA. And the materials properties are described as: Modulus of elasticity E=206.85GPa, Yielding strength Y = 206.85MPa, Density ρ = 7850 kg/m^3,Poisson ratio ν = 0.3, Tangential modulus Et=250MPa. strain rate is taken into account by using the Cowper-Symonds model[14].

$$\frac{\sigma_0^1}{\sigma_0}=1+\left(\frac{\dot{\varepsilon}}{C}\right)^{\frac{1}{P}} \qquad (1)$$

where σ_0^1 is dynamic yield stress, σ_0 is static yield stress. $\dot{\varepsilon}$ is strain rate. C=40.4s^{-1}, P=5.0.

In the analysis, the air and water are modeled with Material Type 9(*MAT_NULL) in LS-DYNA. The relationship between the pressure and the volume of water is given by Gruneisen state equation as follow:

$$P=\frac{\rho_0 C\mu[1+(1-\frac{\gamma_0}{2})\mu-(\frac{\eta}{2})\mu^2]}{[1-(S_1-1)\mu-S_2\frac{\mu^2}{(1+\mu)}-S_3\frac{\mu^3}{(1+\mu)}]}+(\gamma_0+\eta\mu)e \qquad (2)$$

where e is the internal energy per unit volume, C is the intercept of the us-up curve, S1, S2, and S3 are the coefficients of the slope of the us-up curve, γ_0 is the Gruneisen gamma, and η is the first-order volume correction to γ_0. Specific parameters see Table 2

Table 2 The water parameters of The gruneisen equation of state

ρ (kg/m^3)	C(m/s)	S_1	S_2	S_3	Υ_0
1250	1480	2.56	-1.98	0.22	0.49

The state equation of air is defined by Linear-polynomial equation[15],which described as Follows:

$$P=C_0+C_1\mu+C_2\mu^2+C_3\mu^3+(C_4+C_5\mu+C_6\mu^2)e \qquad (3)$$

where e is the internal energy per unit volume. Specific parameters see Table 3.

Table 3 The air parameters of the polynomial equation of state

ρ (kg/m^3)	C_O	C_1	C_2	C_3	C_4	C_5	C_6
1.29	0	0	0	0	0.4	0.4	0

In order to have a comparative study of hybrid sandwich structures with V-type corrugated cores. The panels are filled with two different densities of polyurethane foam. The stress-strain curves of the present polyurethane foam are depicted in Fig.2. The Curve of polyurethane foam with the density of 31kg/m^3 is According to Ref.[16], and a quasi-static compression test was performed on samples to get the curve of the other one. The filler is modeled with Material Type 63 (*MAT_CRUSHABLE_FOAM) in LS-DYNA.

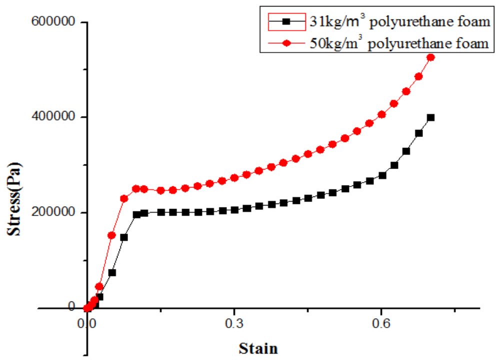

Fig. 2. The compressive stress-strain curves for the polyurethane foam

Finite element model and verification. Fig.3 shows the finite element model adopted in the simulation. The face sheets and cores of HSS are modeled as Lagrangian Belytschko-Tsay shell elements, water and air are modeled as Euler solid elements. The foam filler is modeled as Lagrangian solid elements.

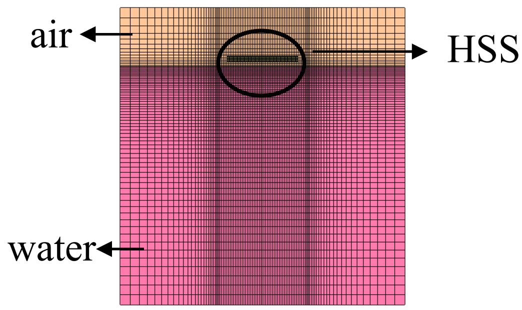

Fig.3 finite element model

In order to verify the mesh density and obtain the contact stiffness in penalty based contact algorithm, the pressures(five positions, see Fig.3) of numerical simulation results for V-type corrugated core sandwich panel are compared to the experimental data. The geometry and material parameters of the simulation model all have given in the above section. Water impact velocities employed in experiment is 4.852m/s, tf=tb=3.0mm, tc=1.0mm. As shown in Table. 4. It is clear that the numerical results are very close to the experimental values.

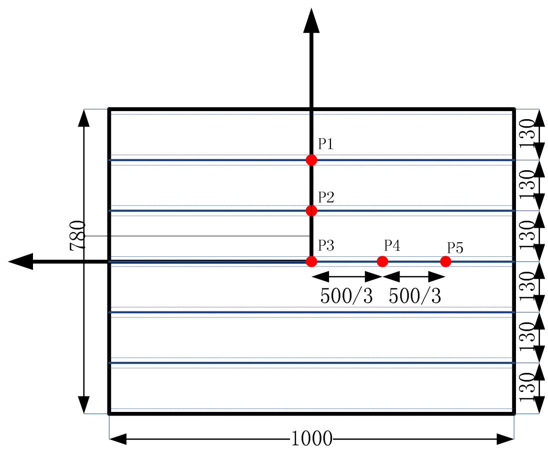

Fig.4 pressure sensor locations on the plate

Table.4 Hydroelastic pressure results for V-type corrugated core sandwich panel

	P1	*P2*	*P3*	*P4*	*P5*
Pressure-Experiment [KPa]	449.26	675.51	641.7	644.53	526.95
Pressure-Numerical [KPa]	459	571	605	528	505
Relative Error	2.10%	15.40%	5.70%	18%	4.10%

III.Results and Discussion

core webs plastic buckling In this section, for the grasp of the performance in resisting to core webs plastic bucking failure, cases 1~4 have been chosen for a comparative analysis. Fig. 4 is the cross sectional profiles of V-type corrugated core sandwich.

From Fig. 4 we can see that the panels with the density of 31 kg/m^3 and 50 kg/m^3 polyurethane foam filler have better performance in resisting to core webs plastic buckling failure compared to those without polyurethane foam filler under the same weight. This is because that the core webs are supported by foam filler which prevent the bars to generate wrinkle.

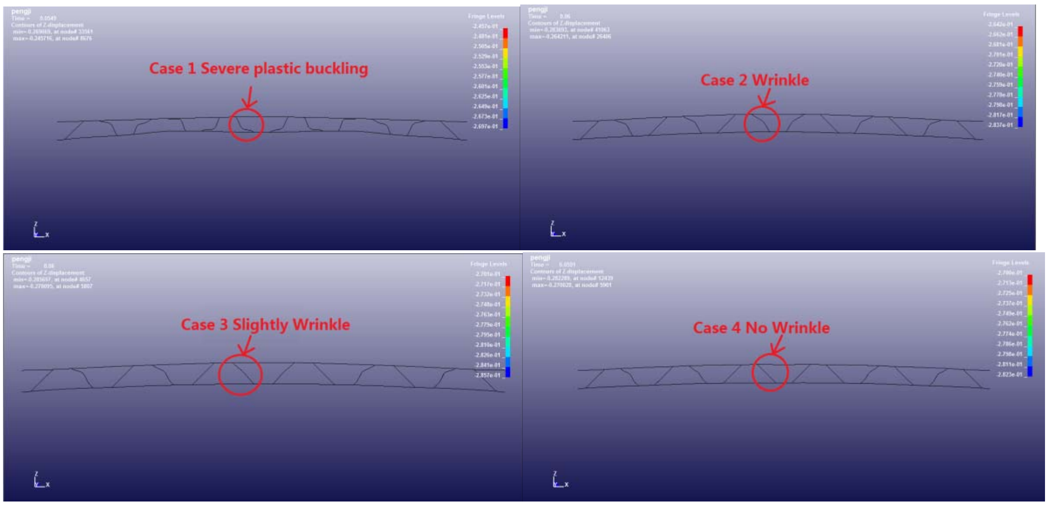

Fig. 4 comparative analysis for core webs plastic buckling

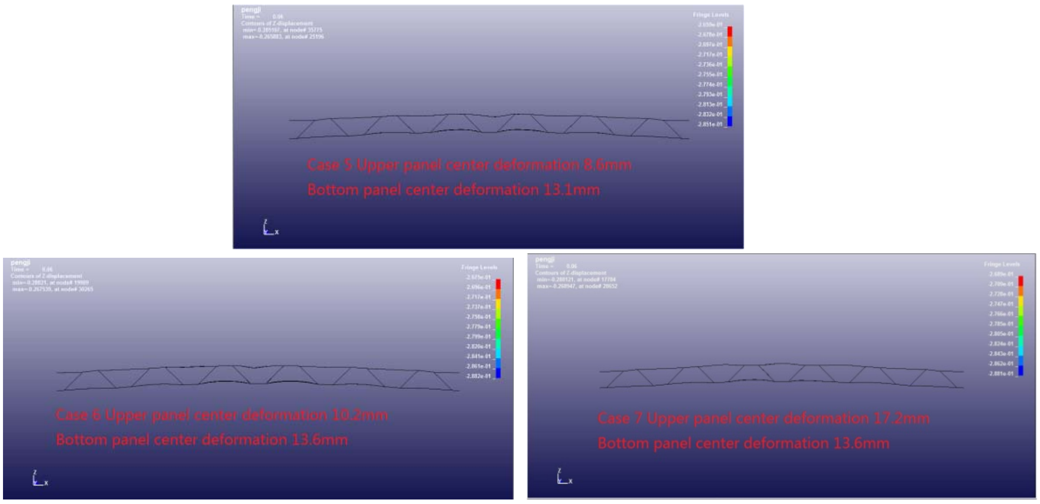

Fig. 5 comparative analysis for Face sheets stretching and bending deformation

Face sheets stretching and bending deformation. In this part, for the study of the performance in resisting to face sheets stretching and bending deformation, cases 5~7 have been chosen for a comparative analysis.

From Fig. 5 we can see that the deformation of central point in bottom panel in these three cases are almost the same. This is probably because the foam filler provided the stiffness for structure is too small compared with steel material. Besides, the deformation modes differ widely between the panels with the density of 31kg/m^3 and 50kg/m^3 polyurethane foam filler. The deformation mode of the panels with the density of 31kg/m^3 and those without polyurethane foam filler are almost the same, which is a type of concave-down deformation in the middle of the back face sheet. However, a type of concave-up deformation mode was observed in the middle of the back face sheet of the panels with the density of 50 kg/m^3. The deformation of central point in upper panel at case 6 is much less than panels with foam filler. This could be caused by the fact that the central part of upper panel is extruded by foam filler at the case 6 and 7, while at the case 5 which is the panel without foam filler the loading directly

transmit to upper panel by cell bar and conduct a moment in the central cell which generate a concave-down deformation.

IV.Conclusions

A numerical simulation study has been conducted to investigate the dynamic response and failure mechanism of hybrid sandwich structures with V-type corrugated cores under water impact using the code LS_dyna. (i) The numerical investigations presented in the paper lead to the following conclusions: The panels with the density of 31 kg/m^3 and 50 kg/m^3 polyurethane foam filler have better performance in resisting to core webs plastic buckling failure compared to those without polyurethane foam filler under the same weight. (ii) The panels with the density of 31 kg/m^3 and 50 kg/m^3 polyurethane foam filler do not have better performance in resisting to face sheets stretching and bending deformation compared to those without polyurethane foam filler under the same metallic structure.

(iii) For the same metallic structure, the deformation modes differ widely between the panels with the different density.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the National Natural Science Founding of P.R. China (under the contract number of 51279065)

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