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Finite element analysis of structural components of sandwich ship

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Abstract*: The use of sandwich panels in ship building enabled the structural components to be made of light weight. Its application to small craft have almost been well established because of the high out of plane bending stiffness. Classical laminated plate theory, first order shear deformation theory and higher order theories are used for the analysis of sandwich plate to evaluate the stresses and stress recovery at the ply level are tedious. A finite element method can be used to obtain the global deflection and the stresses developed in the face sheets, core and at the interfaces. The present study brings out the analysis of components of sandwich using finite element software MSC Nastran.***

Keywords: *Sandwich, face sheet, core,deck,bulkhead, hull;*

I. STRUCTURAL COMPONENTS MADE OF SANDWICH PANEL

Sandwich panels have been used since early and mid 1980s and these have established as major construction component for hull, deck and superstructures of large vessel such as high speed passenger ferries [1]. The construction of a sandwich panel is a particular form of composite construction in which two relatively thin stiff and strong faces are separated by thick core material. The thick foam sandwich construction enabled the faces to be made of very thin sections. Because of the high out of plane stiffness of sandwich composites it has been widely used for the construction of boats hull. Sandwich materials such as fiber reinforced polymer face sheets with foam or honeycomb cores are resistant to marine environment mainly in the aspect of corrosion and due to its high flexibility it performs much better under impact loads. The major structural components in ship structure made of sandwich include deck, bulkhead and hull.

II. NECESSITY OF SANDWICH CONSTRUCTIONS IN SHIP STRUCTURES

The need for developing new material in ship building industry is to make the production, operation, repairs and finally the disposal energy efficient. Thus better performance is expected from less quantity of the material and at reduced cost which imply to reduce the weight at the same time to give higher performance results. In marine applications the structures must have the capability to resist the dynamic loads such as slamming loads for a commercial vessel and loads due to explosions for a military vessel. A flexible material suits more to such structures which are subjected to the action of impact loads, due to which it could absorb the energy during impact and release it there by creating an elastic deformation. Composite materials such as fiber reinforced polymer have been introduced which possess low stiffness compared to the steel but due to its lighter weight thicker sections are used thus resulted in over design than the requirement. Finally sandwich constructions are employed which increased the stiffness compared to composite material by adding a low density core in between the upper and lower facing skin thereby enhancing its bending stiffness with only slight variations in weight. Thus sandwich construction due to its high longitudinal stiffness eliminated the need of stiffening the structure. In short by the use of sandwich materials in ship structure the structural weight could be reduced thereby increasing the pay load and operational speed .Sandwich materials are widely used in naval application due to its low magnetic and radar signature.

III. MATERIAL USED FOR SANDWICH CONSTRUCTION

Face sheet of the sandwich is made of metals alloys or composites and core can be made of balsa, honeycomb or foam. Reinforcements used for the composite face sheets include glass, carbon and polymer fibers. Resin system adopted depends on its mechanical performance commonly used systems include polyester, vinylester or epoxy resins.

Glass fiber includes two varieties viz; E glass and S glass. Compared to E glass the tensile strength of S glass is high and possess good fatigue resistance but it has lower resistance to compressive loading. Carbon fibers are stiffest compared to other fibers but expensive compared to glass fibers hence not widely used in marine applications.

Balsa wood is used in the area such as bulkheads and internal decks which are not exposed to water Because of its less resistance to water penetration. Foam cores may be polyvinylchloride (PVC) foam, polyurethane foam, syntactic foam etc. PVC foam are of two types viz; linear PVC and cross linked PVC foam. The linear PVC foam core is ductile and having low strength compared to crosslinked PVC foam which is brittle in nature. Honeycomb core enables the structure to be lightweight, but due to the difficulty present in bonding with face sheet and risk of water absorption its use is limited. In manufacturing of sandwich, the facing skin, core and the entire sandwich is created in a single step and thus it make possible to construct it in any complex form. Hand layup, vacuum moulding, resin transfer moulding and prepreg consolidation are different methods of manufacturing. In vacuum moulding a female mold is used where as in resin transfer moulding a two sided mould is used which permits to control the geometry and surface finish on the two face part.

IV. DESIGN LOADS

Loads acting on the ship structure can be grouped into those acting on the whole ship by considering it as a girder and those which acts locally on the structural elements. As per *DNV rules* [5] part 3 chapter 1 section 3 A101 and A102 loads relevant for analysis for the craft with hull form of length (L)/depth (D) ratio less than 12 and length less than 50 is only the local loads where as for craft with L/D ratio greater than 12 and length greater than 50, hull girder loads must be considered for the structural analysis.

For a ship structure static and dynamic loads contribute to the overall hull girder bending moment. Treating the ship as longitudinal hull girder or box girder the loads include the longitudinal bending and shearing. To avoid the complexity in the calculation of dynamic load, empirical formulations uses a factor of safety that could be applied to the stresses calculated from the static analysis. Hull girder loads include still water bending moments, wave bending moments, inertial forces due to the ship oscillations, torsional loading etc. Still water bending is induced due to the unequal distribution of the weight and buoyancy acting on the ship when it is floating in still water in equilibrium. Wave bending moments are caused due to the varying loads as a result of motion of the ship and the wave motions. Acceleration experienced by the vessel vary as a function of space coordinates and this results in variation of the weight distribution throughout the length of the ship due to the induced inertial forces. For ship having large deck openings it is found that torsional loadings also have a considerable effect.

Local loads on the structure are out of plane loads acting normal to the surface either distributed over the area or concentrated at a point. The distributed loads include hydrostatic load calculated from the first principles and hydrodynamic loads are evaluated by increasing the static pressure with a factor which relates the ratio of the dynamic strain to the static strain. For the global as well as local loads fatigue nature of this loading should also be taken into account because for a sandwich ship structure it is very critical in details due to stress concentration. Thus the ship structure has to withstand the hull girder bending loads, impact loads and also the loads on the deck and the deck and the bulkhead. The side shell laminate of the hull is subjected to transverse loading due to the hydrostatic forces. Bottom shell laminate subjected to impact from slamming load which is very critical due to its dynamic nature. The deck plate is under compressive loading due to crew, equipment cargo loads etc. The bulkhead is subjected to the transverse loading and the inplane compressive loading from the deck.

V. STRUCTURAL BEHAVIOUR AND FAILURE MODES

In a sandwich structure the core distributes the loads and stresses over a large area; hence the effect of load is reduced due to this sandwich action. The core absorbs the impact stresses, shock loads and the torsional loads. The deflection of the sandwich panel is due to bending deflection which depends on the tensile and compressive modulus of the facing and shearing deflection is dependent on the shear modulus of the core. The behaviour of the sandwich structure can be explained in a micromechanics level, macromechanics level or structural level. In micromechanics the property of the constituent is averaged to obtain the property of the individual elements. In macro mechanic level the average property of the face sheet in a direction along the fiber alignment and perpendicular to it is considered. In structural level, the global behaviour of the structure ie. the behaviour of the sandwich with face sheet bonded to core is considered. The structural behaviour of the sandwich panel depends on non zero terms in the elasticity matrices of a sandwich element. For a balanced and symmetric laminates there will be no extension/bending coupling or extensional shear coupling

The normal stresses developed in the ship structure increases with increase in neutral axis depth. For hogging condition the deck will be in tension and the bottom shell platings under compression and vice-versa for the sagging condition. Side shell of the hull suffers from tension above the neutral axis and compression below the neutral axis under hogging condition.

Under the action of inplane tensile forces face sheet yielding occurs otherwise there will be failure called as debonding of the face sheet from the core. Due to this tensile forces there develops interlaminar shear stress at the interface. This interlaminar shear stress causes the development of normal stresses in the thickness direction at the interface. If this stress exceeds the strength of the adhesive the face sheet debonding will occur. Debonding type of failure is also observable in fatigue loading of the sandwich structure. The crack developed will be in the compression side and it grows parallel to the beam or panel up to the critical length and then it kink on the tension side of the beam and finally results in debonding. When sandwich plate is subjected to transverse loading, it creates normal stresses in the face sheet and shear in the core.

The behaviour of the sandwich panel subjected to inplane compressive loading may be global buckling, face sheet wrinkling, crimping or intra cellular buckling. Wrinkling is a particular type of local instability in which the wave length of the buckled form is same as that of thickness of the core. Wrinkling can be of two modes, symmetric mode or unsymmetric mode. Crimping is the shear failure of the core due to inplane loading. Intra cellular buckling or dimpling is the buckling of the face sheet between the cell walls of the honey comb core. The global buckling occurs at loads greater than that of the wrinkling load. Thus the failure modes in the sandwich material are characterized by tension failure of faces, wrinkling failure due to compressive stresses, shear failure of the core or adhesive.

Failure of the sandwich composite may assume due to the failure of individual layers and failure criteria have been developed in case of each layer. The criterias include maximum stress theory, maximum strain theory, deviatoric or distortion strain energy criteria of Tsai-Hill and interactive tensor criteria of Tsai-Wu [13]. Maximum stress theory states that failure occurs when the stress component developed in any of the material axis is greater than the strength of the material in that direction and is applicable to brittle modes of failure. According Maximum strain theory, the failure occurs when the strain component in a particular direction exceeds the ultimate strain of the material. Tsai-Hill and Tsai-Wu criteria which is a modified form of von Mises criterion and it considers the interaction between the stresses.

Fatigue behaviour of the sandwich structure is different from the metals. It includes fiber breakage, matrix cracking, delamination and interfacial debonding. These failures are caused due to the initial failure of core and the fatigue strength was very close to the strength of the core.

Impact performance of the panel could be explained by considering the amount of the energy absorbed. Thin face sheets will suffer failure due to the impact load and the failure will be characterized by the fiber failure, matrix cracking and delamination. Depending on the type of the core the failure due to impact load will be crushing resulting in the densification of the core without the formation of crack or fracturing the core leaving a cavity .

VI. BOUNDARY CONDITIONS

In ship structures the boundary conditions of the panel are defined by the attachment of bulkhead and the stiffener. The actual end conditions of the sandwich panels are normally in between fixed and pinned.

VII. IDEALISATION OF THE STRUCTURE

The structure of bulkhead, deck and shell plating is idealised as plates with simply supported boundary condition.

VIII. FINITE ELEMENT ANALYSIS OF SANDWICH PANEL

A Elements used for analysis

The elements used for sandwich structures can be classified based on equivalent single layer theory, layerwise theory or three dimensional elasticity theories. In equivalent single layer model the sandwich plate is idealised as an equivalent single plate with complex constitutive behaviour and analysed as a 2D problem using classical laminated plate theory or first order shear deformation theory. In layerwise model the sandwich plate is modeled by stacking the core in between the face sheet as individual layers 2D or 3D model could be used. In 3D modeling the individual elements are modeled as solids and it clearly defines the stresses at the interface.

Real structure is 3D but not modeled as 3D except when 3D complex stress fields are required. For balanced layup the elements need to only predict the inplane behaviour therefore 2D elements may be used. In Nastran shell elements available for modeling layered composites are CQUAD 4, CTRIA6, CQUAD8, and CTRIA3. CQUAD 4 element have 4 nodes at the corners and this element is used in present study.

B Numerical example

MSC Nastran is used to analyse a sandwich panel the sandwich is modeled as a laminated composite by stacking a core in between the face sheet which is a 2D layered model. In 2D layered model the in plane normal and shear stress developed in the three layer viz upper face, core, lower face are obtained layer by layer, where as transverse shear stress obtained on the distinct layer indicates the interlaminar stresses developed between the face and the core.

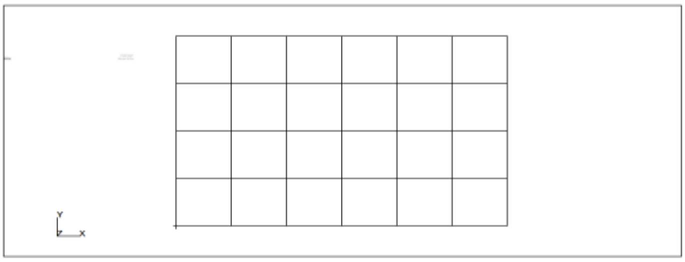

Fig. 1 Finite mesh in 2D layered model

Table 1 Properties of the plate

Face sheet –Carbon epoxy	Core H00PVC Foam
E_1=125GPa	E=160MPa
E_2=5GPa	G=60MPa
G_{12}=2.5GPa	ν=0.32
ν $_{12}$=0.25	h_c=16mm
h_f=2mm	
Plate dimensions a=1500mm, b=1000mm	
Transverse sine load q= q_0 sin(πx/a)sin(πy/b)	
Maximum Transverse load q_0=100N/m²	

CQUAD 4 elements are used for meshing the plate Fig 1 shows the meshed plate. The properties of the sandwich plate used for the analysis and the magnitude of the transverse load are given in the table 1. The boundary conditions used for the analysis are simply supported boundary conditions.

C Results and discussion

The results obtained from the software are tabulated in Table 2. Stress resultants are layer wise for each layer and the deflections obtained is for the whole sandwich plate. It is observed that the inplane normal and shear stresses are obtained for each layer but the transverse shear stress resultant at the two layers remains the same which are the stresses at the interface. In the faces the normal stress values are higher than that of the shear stresses. There is no inplane stresses developed in the core. The output of the Nastran for the displacement of the plate in the transverse direction is shown in Fig 2. The deflection obtained at the centre is 0.0948mm.

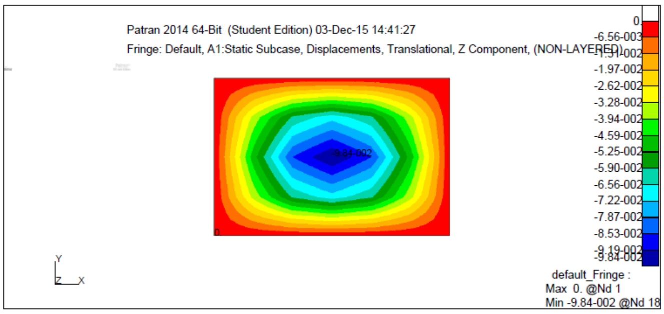

Fig. 2 Output –Deflection of the plate in the transverse direction

Table 2 Stress resultants 2D layered model –output of Nastran

<table>
<tr><td colspan="4">Inplane stress resultant(N/mm2)</td></tr>
<tr><td></td><td>Upper Face</td><td>Core</td><td>Lower Face</td></tr>
<tr><td rowspan="2">σ_{xx}</td><td>0.348</td><td>0</td><td>-0.348</td></tr>
<tr><td>0.0386</td><td>0</td><td>-.0386</td></tr>
<tr><td rowspan="2">σ_{yy}</td><td>0.0387</td><td>0</td><td>-.0387</td></tr>
<tr><td>0.0043</td><td>0</td><td>-.0043</td></tr>
<tr><td>σ_{zz}</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">τ_{xy}</td><td>+0.00219</td><td>0</td><td>+.00219</td></tr>
<tr><td>-0.00219</td><td>0</td><td>-0.00219</td></tr>
<tr><td colspan="4">Transverse shear stress resultant at the interfaces</td></tr>
<tr><td colspan="2"></td><td>Interface 1</td><td>Interface 2</td></tr>
<tr><td colspan="2">τ_{xz}</td><td>$7.16x10^{-4}$</td><td>$7.16x10^{-4}$</td></tr>
<tr><td colspan="2">τ_{yz}</td><td>$2.91x10^{-3}$</td><td>$2.91x10^{-3}$</td></tr>
</table>

IX. ANALYTICAL SOLUTION

The classical laminated plate theory and the first order shear deformation theory given in [2] are used to analyse a sandwich panel with properties as shown in table 1,under a sinusoidal load with intensity q_0 . The central deflections in the transverse direction of a sandwich plate using classical laminated plate theory is obtained as 0.0529mm and using first order shear deformation theory as 0.06017mm.

X. CONCLUSION

A transversely loaded sandwich plate is analysed using classical methods and finite element methods. The deflections obtained from the finite elements method is greater than those obtained from the classical laminated plate theory and first order shear deformation theory.

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