TRANSIENT HEAT TRANSFER ANALYSIS OF BULKHEAD PENETRATION PIECE FOR A-CLASS COMPARTMENT OF SHIP AND OFFSHORE PLANT

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Abstract - In order to protect people's lives in the event of a fire and to prevent large-scale damage accidents,ClassificationSocieties have strengthened the relevant design rules to prevent flames from being transmitted from the firing point to other compartments.In compartments where fire protection is important, such as A-class compartments, the airtightness and fire protection design of members that pass through bulkheads and decks are strictly regulated by the International Maritime Organization's (IMO) Safety of Life at Sea Convention (SOLAS).In order to verify the suitability of the fire protection design for such penetration members, the fire test prescribed by the Maritime Safety Committee (MSC) must be performed, but numerical analyses are need to be carried out to minimize the time and cost required for the test.In this study, the transient heat transfer numerical analysis based on the finite element method was applied to investigate the heat transfer characteristics of the bulkhead penetration piecefor the A-class compartments. The transient heat transfer analyses were carried out according to the MSC fire test procedure, and the heat transfer characteristics of the bulkhead penetration piecesof various materials were reviewed.

Index Terms - A-class compartment, Bulkhead penetration piece, Fire accident of ship and offshore plant, Transient heat transfer analysis.

I. INTRODUCTION

In order to protect people's lives in the event of a fire and to prevent large-scale damage accidents, Classification Societies have strengthened the design rules of fire protection for cargo hold and accommodation compartments to prevent flames from being transmitted from the firing point to other compartments.In the compartments where fire protection is important, such as A-class compartments, the airtightness and fire protection design of members that pass through bulkheads and decks are strictly regulated by the International Maritime Organization's (IMO) Safety of Life at Sea Convention (SOLAS) [1].In order to verify the suitability of the fire protection design for such penetration members, the fire test prescribed by the Maritime Safety Committee (MSC) [2] must be performed, but numerical analyses are need to be carried out to minimize the time and cost required for the test.

A number of studies have been conducted on the heat transfer analysis in relevant to the ship and offshore plant.Zhou et al. [3] carried out numerical simulations to analyze the thermal behavior of cutting access openings in a ship hull using flame cutting.Murawski[4] conducted the thermal deformation analyses of the shaft line of the propulsion system and the crankshaft connected to the main engine for the low speed engine installed in 3,000 TEU container ship.Barletta et al. [5] carried out transient heat transfer analysis for subsea pipes under a start-up working conditions in cased that the pipe temperature were reached suddenly to the uniform temperature at the same initial temperature as subsea soil temperature, and the uniform temperature was reached smoothly.As surveyed in the previous literatures, it can be seen that there are few cases of studies on the numerical analysis of heat transfer in the A-class penetration piece in relation to ship and offshore plant.

In this study, the transient heat transfer numerical analysis based on the finite element method was applied to investigate the heat transfer characteristics of the bulkhead penetration piece for the A-class compartments. The transient heat transfer analyses were carried out according to the MSC fire test procedure [2], and the heat transfer characteristics of the bulkhead penetration pieces of various materials such as brass, S45C, and SUS316L were reviewed.

II. THEORETICAL BACKGROUND

Convection is one of the heat transfer phenomena that occurs between a solid surface and an adjacent liquid or gas that flows, and is effected by a combination of conduction and fluid motion.Convective heat transfer depends not only on the fluid velocity(v)but also on the kinematic viscosity(μ), thermal conductivity(k), density(ρ), and specific heat(C_p), which are physical properties of the fluid.It is also related to the roughness of the solid surface and the type of the fluid flow.The convective heat transfer rate is proportional to the temperature difference, and is expressed as Newton's law of cooling as follows [6]:

$$\dot{q}_{conv} = hA_s(T_s - T_\infty) \quad (1)$$

whereA_s is the area where convective heat transfer occurs, T_s is the surface temperature, and T_∞ is the

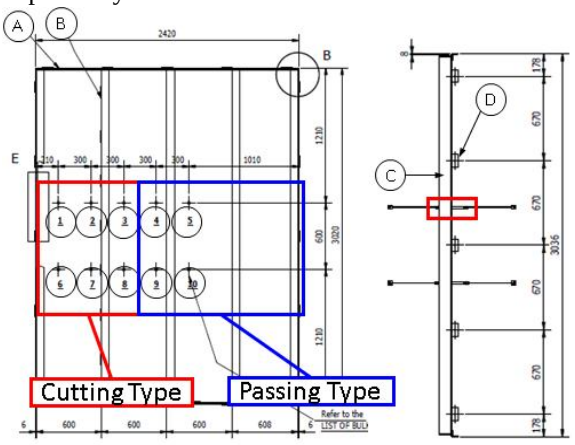
temperature of the fluid far enough away from the surface.hisalso the convective heat transfer coefficient and is defined as follows:

$$h = \frac{-k_{fluid}\left(\frac{\partial T}{\partial y}\right)_{y=0}}{T_s - T_\infty} \quad (2)$$

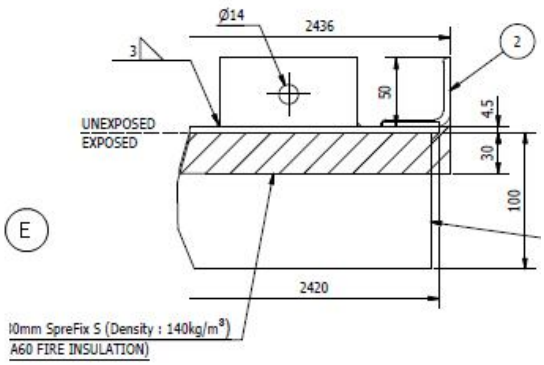
The convective heat transfer coefficient can be obtainedas the temperature distribution in the fluid is known by equation (2).

III. TRANSIENT HEAT TRANSFER ANALYSIS

The specimen design was carried out in accordance with the specimen specifications regulated in the MSC's fire test procedure [2]. The arrangement of the penetration pieces and the configuration of the thermal insulation material are shown in Fig. 1 and Table 1, respectively.



(a) Overall configuration



(b) Detailed insulation configuration

Fig. 1 Specimen design for MSC fire test

Table 1 Material type and main dimension of test specimen

No.	Part Name	Main Dimension	Material Type
1, 4	Penetration Piece	ψ18Socket/ (ψ8Tube)	SUS/SUS
2	Penetration Piece	ψ18Socket/ (ψ8Tube)	S45C/Brass
3, 5	Penetration Piece	ψ18 Socket/ (ψ8 Tube)	S45C/S45C
6, 9	Penetration Piece	ψ26 Socket / (ψ12 Tube)	SUS/SUS
7	Penetration Piece	ψ26 Socket/ (ψ12 Tube)	S45C/Brass
8, 10	Penetration Piece	ψ26 Socket/ (ψ12 Tube)	S45C/S45C
A	BHD Plate	2420x2480x4.5t	Mild Steel
B	BHD Stiffener	65x65x6t	Mild Steel
C	Sealing	100x4.5x2420L	Mild Steel
D	Mounting Plate	80x80x4.5t	Mild Steel
E	Fire Insulation	60t / 90t	Spray S

The finite element analysis model used in this study was generated using tetrahedral solid elements based on fire test specimen design shown in Fig. 1.The shape of the finite element model is shown in Fig. 2.

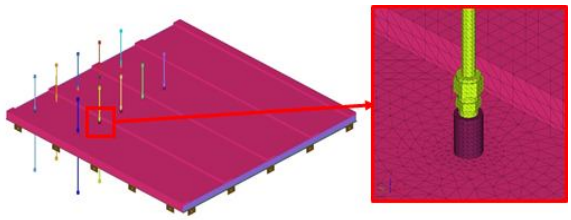
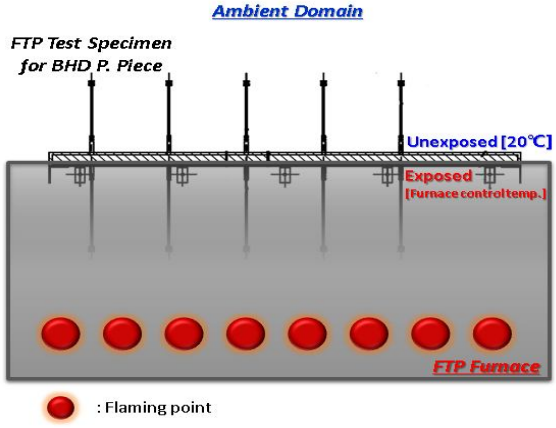


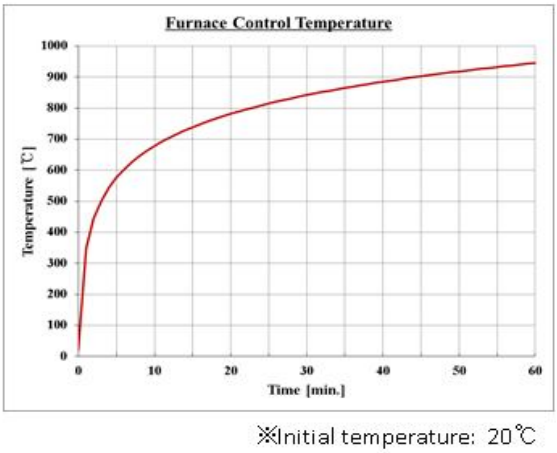
Fig. 2 Finite element model for test specimen

As shown in Fig. 2, the detailed finite element modelingwas considered to precisely simulate the shapes of the penetration tube and connecting parts, where the temperature results should be observed.The number of finite elements and nodes used for numerical analysis are 1,283,696 and 303,675, respectively.The heat transfer coefficient, specific heat, density and convection coefficient applied to the numerical analysis model were calculated considering the characteristic values according to the temperature change of 20 ~ 900 ℃.The heating conditions were set to be same as the conditions specified on the Fire Test Procedure (FTP) of the MSC as shown in Fig. 3.



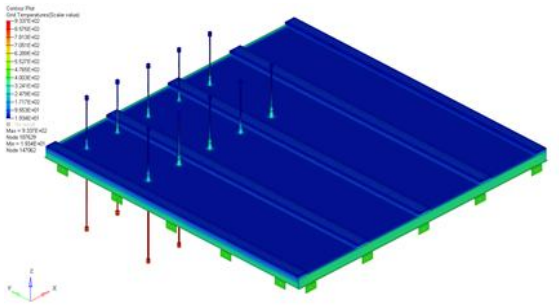
(a) Fire test configuration

$$T = 340\log_{10}(8t + 1) + 20 \quad [°C]$$

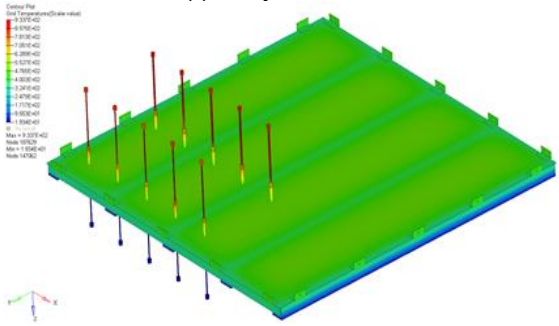


(b) Furnace control temperature
Fig. 3 Fire test configuration and furnace control temperature

Fig. 4 shows representatively the results of the transient heat transfer analysis of the temperature distribution for the test specimen of the bulkhead penetration pieces heated from 20 ° C to 930 ° C for 60 minutes as specified in the MSC's fire test procedure.



(a) Unexposed surface



(b) Exposed surface
Fig. 4Temperature contour results

As shown in Fig. 4, the temperature distribution of the exposed surface of test specimen being contact to the flame after 60 minutes of heating was 390 ~ 930 □ while the temperature distribution of the unexposed surface was 20 ~ 320 ° C.The temperature distribution specified in the MSC fire test procedure is limited to below 180 ° C on the unexposed surface after 60 minutes of heating.From the results of the transient heat transfer analysis, it was found that the penetration pieces of all materials excluding the SUS material did not satisfy the temperature limit specified in the MSC fire test procedure.

CONCLUDING REMARKS

In this study, a numerical method of transient heat transfer based on the finite element analysiswas applied to investigate the heat transfer characteristics of bulkhead penetration piecesinstalled to theA-class compartment.The materials of the penetration piece were the brass, SUS, and S45C materials which are widely applied to general merchant ships.The temperature distribution over time was numerically analyzed based on the design shape of length and diameter for the penetration pieces of various materials. From the transient heat transfer analysis results, the temperature distribution of the exposed surface of test specimen being contact to the flame after 60 minutes of heating was 390 ~ 930 □ while the temperature distribution of the unexposed surface was 20 ~ 320 ° C. It was found that the penetration pieces of all materials excluding the SUS material did not satisfy the temperature limit specified in the MSC fire test procedure.The authors will carry out the transient heat transfer analyses according to changes in the shape of the bulkhead penetration piece and the insulation materials, and conduct an actual fire test to compare and verify the numerical analysis results.

ACKNOWLEDGEMENT

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