Research of flammability of fireproof materials in ship safety

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Abstract. This paper analyzes the classification, performance and application of ship fireproof and heat insulating materials, and describes the test standard and performance evaluation criteria of the non-combustibility, low flame-spread characteristics and smoke and toxicity of marine fireproof materials in detail. So the paper has certain reference value and guidance significance for the selection of heat insulating materials with fire divisions and the use of flammable materials on board in accordance with requirements.

In recent years, ship fire accidents have happened continuously. The issue of ship fire prevention has aroused the concern of all countries. There has been a trend in ship cabin interior materials that non-combustible material displacing combustible material. In this aspect, all countries in the world have done a lot of research work. Combustible material are clearly defined in The International Convention for the Safety of Life at Sea (SOLAS) and the relevant amendments [1]. The International High-Speed Craft Safety Code (HSC Code), enacted by the International Maritime Organization (IMO), entered into force on 1 January 1996, which assert claims from prevention, suppression and escape to ensure the safety of life at sea and prevent shipwreck. Fire-proof insulation materials should have a variety of conditions such as light mass, fire proof, heat insulation, sound proof, beauty and so on. One of the most important is the extensive use of a variety of fire-resistant material to constitute fire divisions, which strengthens the fire protection capacity of ship structure.

This paper makes in-depth analysis of the performance, advantages and disadvantages and application on the vessel of some ship fireproof and heat insulating materials, and conduct a comparative study in the main performance of several materials.

2. Overview of ship fireproof and heat insulating material

As Euro-American corporations involve in China's marine development business, there is a higher requirement for fire divisions which are not defined in the Convention so as to safeguard the safety of life at sea better. Fire happening when the ship in operation will cause great loss probably because the fight conditions at sea is worse than that on land. If fire happens when the ship is sailing in heavy sea, fighting difficulties will increase. Therefore, in accordance with the requirements of the SOLAS Convention, the study of fireproof and heat insulating materials with good flame resistance and low flame-spread characteristics is extremely important [2].
China began to study ship fire proof materials in the late 70s of last century, mainly referring to the international popular class of fire divisions, which is generally divided into two types of organic materials and inorganic materials. Organic materials include black cork board, polyurethane foam board, yellow cork board and so on; inorganic materials include asbestos foam board, glass wool insulation board, ceramic fiber and so on. There are many enterprises in China producing inorganic fireproof and heat insulating materials. Fire-resistant materials have been used for on board are mainly PS-2 mineral cotton board, moisture-proof ultra-fine glass wool felt, double-sided aluminum-plastic composite rock wool board, stainless steel composite rock wool board, polyethylene foam board and so on.

2.2. Green marine fireproof material
Green materials, also known as eco-materials, refers to the materials which are in harmony or coexistence with chemical ecology environment in raw material collection, product manufacturing, use or recycling, waste processing and other aspects. Such green fireproof and heat insulating materials are not much produced in China. However, Western countries have a variety of similar green refractory fiber products on the market, such as Firemaster Marine Lite from Thermal Ceramics; Insulfax, Fiberfrax from Unifrax.

3. Classification of fireproof materials
The SOLAS Convention classifies materials into non-combustible materials and combustible materials. As for deck covering and associated low flame-spread surface materials, the classification is based on a specific performance difference. Non-combustible materials in accordance with the main components, application location and fire-resistant rate are classified as follows:

3.1. Classification according to the main components
Classification of non-combustible material according to the main components see the Table 1a and 1b.

| Name              | Characteristics                                      | Main Uses                                           |
|-------------------|------------------------------------------------------|-----------------------------------------------------|
| Sodium silicate   | Sodium silicate as the base material, and a certain filler, curing agent and other semi-liquid material. | As adhesive of heat and sound insulating material and so on. |
| binder            |                                                      |                                                     |
| Cement materials  | Cement mixed with sand and lightweight aggregate.    | As flooring and deck covering with non-combustibility high hardness. |
|                   |                                                      | Heat insulation, but not                            |
| Asbestos products | Natural inorganic fiber asbestos mainly.             | recommended for harmful effect on human health.     |
|                   |                                                      |                                                     |
| Glass cotton      | Manmade inorganic fibre products, weak high-temperature resistance. | General heat insulation and sound absorption material. |
| products          |                                                      |                                                     |
| Rock wool products| Manmade inorganic fibre products, higher high-temperature resistance. | Heat insulation, composite plate as components of bulkhead and deck. |
|                   |                                                      |                                                     |
| Ceramic wool      | Manmade inorganic fibre products, very high high-temperature resistance. | Heat insulation, fire-resistant separation composition, sound absorption material. |
| products          |                                                      |                                                     |
Table 1b. Classification of non-combustible material according to the main components.

| Name             | Characteristics                      | Main Uses                                      |
|------------------|--------------------------------------|-----------------------------------------------|
| Calcium silicate | Artificial synthetic board, high      | Heat insulating material of bulkhead           |
|                  | intensity.                           | plate and ceiling.                            |
| Pearlite plate   | Artificial synthetic board, moderate  | Heat insulating material of bulkhead           |
|                  | intensity.                           | plate and ceiling.                            |
| Vermiculite plate| Artificial synthetic board, low intensity. | Heat insulating material of bulkhead | plate and ceiling. |

3.2. Classification according to application location and fire-resistant rate

Flammability classification is based on the ability to react to fire of materials to determine its fire rating. Flammability ratings for materials or products are traditionally expressed as flammability ratings or flammability index, which is the overall performance of the product is integrated into one or more characteristic parameters. These parameters describe the combustion characteristics of the product during the test. The description of the material reaction to the fire depends on the combustion characteristics of the material and the test method.

There are three kinds of divisions types defined by SOLAS, A-Class, B-Class and C-Class [3]. Class-A is a division made of steel plates and other equivalent materials, which is a structure that can stop smoke and flame from passing through within 1 h. While according to insulation requirements, Class-A division is divided into four grades, and during the time corresponding to each grades, the elevated temperatures without exposure to the surface of the flame must be within the limits specified in the Convention: grade ‘A-60’ 60 min, grade ‘A-30’ 30 min, grade ‘A-15’ 15 min and grade ‘A-0’ 0 min; insulation value of B-Class, in the following two standard fire test time, the average temperature of the side which is back to the flame rises no more than 139 degrees, and the temperature at any point including any of the joints rises no more than 139 degrees; Constructions of grade ‘B-15’ 15 min and grade ‘B-0’ 0 min should prevent the passage of flame at the end of the 0.5 h standard fire test; Class-C divisions are divisions constructed of non-combustible materials. They do not have to meet the requirement of preventing the passage of smoke and flame and limiting heating as long as they meet the relevant requirements. The following is the classification in accordance with the application location and fire-resistant rate of different materials, see Table 2a and Table 2b.

Table 2a. Classification in accordance with the application location and fire-resistant rate.

| Application location | Fire-Resistant rate | Common Materials                                        |
|----------------------|---------------------|--------------------------------------------------------|
| Bulkhead             | A-60, A-30, A-15, A-0, B-15, B-0, C | Steel, heat insulating material, non-combustible materials. |
| Deck                 | A-60, A-30, A-15, A-0, B-0 | Steel, heat insulating material, non-combustible materials. |
| Ceiling              | B-15, B-0, C        | Non-combustible materials.                             |
| Lining board         | B-15, B-0, C        | Non-combustible materials.                             |
| Door, doorframe      | A-60, A-30, A-15, A-0, B-15, B-0, C | A-Class for the steel material, B-Class and C-Class for the non-combustible materials. |
Table 2b. Classification in accordance with the application location and fire-resistant rate.

| Application location | Fire-Resistant rate | Common Materials |
|----------------------|---------------------|------------------|
| Floor                | --                  | Cement grout and Lightweight aggregate concrete. |
| Heat insulating      | --                  | Ceramic wool, rock wool, glass wool board. |
| material             |                     |                  |
| Through position of  | Without destroying  | Combine composite rockwool panel or ceramic plate with materials preventing flame spread. |
| cable                | the fire integrity  |                  |
|                      | of the through      |                  |
|                      | position.           |                  |
| Through position of  | Without destroying  | Marine fire air valve should be conducted a fire division test. |
| of fire air valve    | the fire integrity  |                  |
|                      | and slightly higher |                  |
|                      | than fire divisions class. |                  |

Heat insulating materials with ‘A’, ‘B’ and ‘C’ class fire-resistant fire divisions used in ship must be non-combustible materials; damp-proof layers and adhesives used with insulation and insulation for pipe fittings of cooling systems need not be non-combustible materials, while they should maintain the practicable minimum, and their exposed surfaces should have low flame-spread characteristics. Paints used in exposed surfaces, varnish and other decorative materials and deck coverings should not produce excessive substances with smoke and toxicity. Judging whether the marine fireproof materials have non-combustibility, low flame spread characteristics, smoke and toxicity are determined by the specified test.

4. Flammability of materials

4.1. Non-combustibility

Non-combustible material refers to a material heated to about 750 °C, neither burning, nor giving off sufficient flammable boil-off gas [4]. International marine non-combustible materials are determined by the test procedure specified by FTP Code. The marine material is specified that any material other than non-combustible material is combustible. According to the SOLAS Convention, the material is classified into non-combustible materials and combustible materials. Differently, the building materials are classified into non-combustible materials, fire-retardant materials, combustible materials and flammable materials by China national standard GB8624-1997 [5]. According to China National Standard 1501182-1990 Fire Test-Test Method of Non-Combustibility of Building Materials and the application rules of the procedures of international fire resistance test, the conditions for determining the non-combustibility of the construction material and marine material are shown in Table 3.

In addition to considering the changes of the material’s own performance during the whole test, the current standard should also consider the change of its environmental conditions, which is qualitative technical index. Material non-combustibility is determined by the prescribed test process. The material required to achieve the standard test conditions can be judged as non-combustible materials, and for some non-single-component material, even if the inorganic and organic composite materials, it is said that it has non-combustibility as long as it can meet the criteria for evaluation. Compared with non-combustible materials for buildings, there are higher requirements for marine non-combustible materials, and the average surface temperature rise of the sample is also required indicators.
Table 3. The non-combustibility of the construction material and marine material.

| Determinant conditions of non-combustibility | Average furnace temperature rise | Average burning time of sample | Average surface temperature rise of sample | Average mass loss rate of sample |
|----------------------------------------------|---------------------------------|---------------------------------|------------------------------------------|---------------------------------|
| Non-combustibility of the construction material | ≤50°C                           | ≤20s                            | --                                       | ≤50%                            |
| Non-combustibility of the marine material     | ≤30°C                           | ≤10s                            | ≤30°C                                    | ≤50%                            |

Non-combustible materials are generally inorganic materials. Whether using surface coatings or chemical soaking methods, organic materials can not be changed to non-combustible materials by general processing methods [6]. Organic materials are mainly used for thermal insulation materials used by fire divisions in ships or insulating materials of ventilation pipes, etc. The furnace temperature was controlled and stabilized at 750±5°C by heating resistance wire. Three thermocouples were placed in the furnace and the sample to measure the temperature of the furnace, the surface temperature of the sample and the center temperature of the sample, and the curves of temperature change and time are output through data acquisition.

Select the soft fiber, rigid plate type, semi-rigid categories of three non-combustible materials for use, the non-combustibility curves of the test are shown in Fig. 1. From the comparison of the non-combustibility curves of various materials, it can be seen that the furnace temperature of the fiber material and the surface temperature of the sample reach a constant value in a short time. There is an obvious peak in the center temperature of the rigid plate material, and the final temperature takes a long time to reach a constant. For high density materials, the central thermocouple temperature will slowly reach the highest value, which has a greater impact on the furnace temperature and the temperature difference of the sample surface temperature. The amount of internal combustibles exist in the material that meets the requirements for non-combustibility will directly affect the performance of the material. Combustion and duration of the combustible will directly lead to the furnace temperature and sample surface temperature rising, making the temperature difference of the final equilibrium temperature too high [7].

![Figure 1. The non-combustibility curves of the test.](image)
In general, products made only of glass, concrete, ceramic products, natural stone and commonly used metals and alloys can be considered non-combustible materials which can be used onboard without test and approval.

4.2. Low flame-spread characteristics

Low flame-spread characteristics refers to the surface material can effectively limit the spread of the flame. This characteristics is assessed by the FTP Code. surface material flammability test, tested by the fire test procedures for the surface flammability of bulkheads, ceilings and deck decorative materials in accordance with Resolution A653 (16) passed by IMO. Specific marine low-flame-spread materials are bulkheads, linings, ceilings and the like, such as film, decoration layer and so on; surface paint, varnish, coating and so on; moisture barrier and adhesives used with insulation and the exposed surface of the insulation for pipe fittings of cooling system; deck covering, floor covering(carpet), ventilation pipe and so on.

The general low-flame-spread test apparatus provides a method of evaluating the combustion characteristics of a sample in the vertical direction. The sample is exposed to a graded radiation flow field provided by a gas-fired radiant panel, and the radiation surface is close to the ignition source. Meanwhile, observe the ignition time, flame spread and extinguishment of the sample, and measure the millivolt voltage signal of thermocouple in the combustion process. Heat for ignition, sustain burning heat, critical heat flux during extinguishment and the value of thermal release can be obtained by the temperature and information collection module. Marine flammable materials to meet the performance requirements of low flame-spread characteristics are shown in Table 4.

| Low flame spread characteristics performance criteria | Critical heat flux during extinguishment | Sustain burning heat | Total value of thermal release | Peak value of thermal release |
|------------------------------------------------------|----------------------------------------|---------------------|--------------------------------|-----------------------------|
| Bulkhead, lining board, damp-proof layers and adhesives, the exposed surface of the insulation for pipe fittings of cooling system and plastic pipe Deck base covering and floor covering | \( \geq 20 \text{KW/m}^2 \) | \( \geq 1.5 \text{MJ/m}^2 \) | \( \leq 0.7 \text{MJ} \) | \( \leq 4 \text{KW} \) |
| | \( \geq 10 \text{KW/m}^2 \) | \( \geq 0.25 \text{MJ/m}^2 \) | \( \leq 1.5 \text{MJ} \) | \( \leq 10 \text{KW} \) |

4.3. Smoke and toxicity

It is necessary to reduce the life risk caused by smoke and toxic substances on board in the event of fire. Therefore, flammable materials, surface coatings included, flammable gases and toxic substances released from the fire should be restricted to effectively control potential smoke and toxicity. Smoke generation tests should be carried out in accordance with smoke and toxicity test in FTP Code Part Z and International Standard 1505659: 1994.

Marine flammable materials which are needed doing the smoke and toxicity test involve paints, varnishes and other decorative coating for exposed surfaces as specified in n-2, section 6 of the SOLAS Convention. According to Appendix 2 of FTP Code, when the decorative material and the deck covering cannot simultaneously satisfy the total heat release value Q of not more than 0.2MJ and the heat release rate peak Qp of not more than 1.0 kw, further testing of smoke density and toxicity is required for validation. These include: decorative materials for bulkheads, linings or ceilings, such as
films and decorative veneers; deck coverings materials, such as deck base coverings; materials used on the surface of floors, such as carpets; plastic pipes and cables; paints, varnishes and other decorative coating for exposed surfaces.

The general test equipment can collect and measure the amount of smoke generated on the surface of a horizontally placed sample in a closed combustion chamber with or without the use of ignition conditions under specified heat radiation conditions. The combustion chamber is equipped with a photometric test device, which can measure attenuation of beam through the smoke and represent smoke volume in the form of a specific optical density.

Tests are carried out by accredited laboratories in accordance with FTP rules Part Z. The test should be carried out in three states: (1) With test flames, the irradiation is 25kw/m2; (2) Without test flames, the irradiation is 25kw/m2; (3) Without test flames, the irradiation is 50kw/m2.

5. Conclusion
Flammability of ship fireproofing material is one of the important attributes to evaluate the safety performance of ship. Based on the flame spread and the spread speed, the heat generated when burning and smoke volume and concentration, toxicity, etc. people can judge whether it meets the requirements of marine fireproof materials. As a mobile steel structural buildings on the water, ships will often be subjected to vibration and collision. Sailing in waters with diverse climates is different from the service conditions on land.

Therefore, the approach used on land cannot be simply copied and the particularity of the ship must be considered, that is, to meet the requirements of the ship. In the meantime, when the ship is in operation, the firefighting condition is worse than that on land, so it is more necessary to judge the flammability of fireproof materials. When ship fire breaks out, by passive fire proof of materials, people can maintain the integrity of the ship structure in a certain time, control the smoke and flames in local range, avoid the spreading of the fire, and win time for evacuation and extinguishment in order to minimize casualties and property damage.

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