

**PMI foams meet the IMO HSC Code Criteria MSC.40(64) –
Lightweight composite sandwich solutions for the marine industry**

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March 2002

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He recently guided a system development project to realize the use of weight optimized sandwich structures for high speed vessels complying to various IMO fire regulations.

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ABSTRACT

Fire is a major concern when it comes to selecting materials for marine applications. Requirements to passive fire protection are generally much stricter compared to most other applications, including aerospace. IMO (International Maritime Organization) have established the Code of Safety for **H**igh **S**peed **C**raft (HSC Code) 1 January 1996 were all ships in international traffic have to comply with. All areas in a vessel are divided into “Fire Restricting Material” and “Fire Resisting Division” which has a functional approach to the use of composite materials. This paper describes the use of PMI foams in marine sandwich structures and the realization of weight optimized panel solutions to meet the IMO – High Speed Craft Code (HSC). An introduction into the regulations and the tests series which had to be passed will be given. It will be shown how weight optimized fire-resistant constructions that comply with IMO HSC regulations could be realized.

INTRODUCTION

The introduction of composite materials in the primary and secondary structure of marine vessels increased in the last ten years. Marine vessels like the Norwegian “Skjold” (currently under a U.S. practical test program, see picture1) or the Swedish “Visby” were entirely build from composite materials. Sandwich constructions are the key factor to build lightweight, reliable and durable vessels. In case of a fire the sandwich constructions will be exposed to the tough natural forces of a fire. Temperatures can be as high as 1832°F (1000°C), smoke can be created in large amounts and the structure of the ship can be weakened.

Passive fire protection has a main function for the safety of marine vessels and will give time to evacuate the passengers or protect the ship. This paper will give an overview, how marine vessels can be protected *the light way*.

Regulations To Passive Fire Protection [1]

There is a major difference between SOLAS (Safety Of Live At Sea) and HSC-code requirements regarding the link between structural and insulation materials and passive fire protection.

SOLAS:

For the structure of a ship SOLAS simply states that all structural materials and insulation shall be non-combustible according to IMO Resolution A. 472(XII) (Chapter II – 2, regulation 23 and 34). This excludes all polymeric composites materials from primary or secondary structure. In all fire divisions, even if they are non-load carrying, no combustible materials are allowed. The only allowance for combustible materials on structural elements or partitions in a SOLAS vessel is defined in Chapter II-2, regulation 34, paragraph 4: “ The total volume of combustible facings, moldings, decoration and veneers in any accommodation and service space shall not exceed a volume equivalent to .1” (2,5 mm) veneer on the combined area of the walls and ceilings. In the case of ships fitted with an automatic sprinkler system complying with the provision of regulation 12, the above volume may include some combustible material used for erection of “C” class divisions”. Ventilation ducts shall also be of non-combustible materials (usually steel is required) except from the last 79” (2000 mm) towards termination points. For non-structural elements for the exterior of a SOLAS vessel, there are no fire requirements. This gives an opening for composite materials for e.g. cladding of funnel, swimming pools, fairing panels, etc.

HSC-Code [3]:

In principle, all materials and constructions approved for SOLAS-vessels can be used on a HSC. However, the HSC-code has a functional approach, which gives an opening for other materials / constructions as long as they meet strict criteria to fire reaction.

Six different space categories has been defined by the HSC Code:

- A: Areas of Major Fire Hazard (engine rooms, car deck,...)
- B: Areas of Moderate Fire Hazard
- C: Areas of Minor Fire Hazard (passenger areas,...)
- D: Control Stations
- E: Evacuation Stations and External Escape routes
- F: Open Spaces

Materials that do not comply with the SOLAS regulation must qualify as “Fire Restricting Materials”. Qualified materials / constructions can be used in fire resisting divisions. In May 1999 the IMO adopted some important amendments to the HSC-code fire test procedure, called draft resolution MSC.90(71). This resolution states that fire reaction tests for furniture’s and components other than room linings should be performed according to the standard ISO 5660, the Cone Calorimeter Test. This is a small scale test 3,9” x 3,9” (100 x 100 mm samples) as opposed to the ISO 9705 Room-Corner test, that require 344ft² (32 m²) test samples!

Important Terms In Fire Engineering [1]

The two most important terms in fire engineering are fire reaction and fire resistance. A short and non-scientific explanation is given below.

Fire Reaction:

It describes a material reaction to fire, which is of major importance for the development of a fire in the early stages. Typical fire reaction properties are: heat release, surface flame spread, time to ignition, toxicity, (non-) combustibility, etc. Tests that determine these types of properties are material tests. The surface of a product is often the governing parameter for the fire reaction properties. Traditionally small-scale tests have been used to evaluate the surface, assuming a non-combustible backing. IMO has decided that a full-scale test is needed to qualify the so-called “Fire Restricting Material”, where the structure behind the surface is combustible.

Fire Reaction Test:

ISO 9750 full scale room test for surface products (room corner test). The size of the test cabin is 11,8’ x 7,9’ x 7,9’ – 344 ft² (3,6 x 2,4 x 2,4 m - 32 m²). It must be prepared similar to the end use with all the joints, fixation mounted in the vessel including the surface finish . A propane burner is located in one corner of the cabinet. The output in the first 10 min is 100KW followed by 300 KW for another 10 min. heat release , smoke production, flame spread and heat flux are recorded. The test criteria are fulfilled if:

1. The time average of HRR (Heat Release Rate) excluding the HRR from the burner does not exceed 100kW,
2. The max. HRR excluding the HRR from the ignition source does not exceed 500 kW averaged over any 30 s period of time during the test.
3. The time average of the smoke production rate does not exceed 4,6 ft²/s (1,4 m²/s)
4. The max. value of the smoke production rate does not exceed 27,2 ft²/s (8,3 m²/s) averaged over any period of 60 s during the test.

5. flame spread must not develop any further down the walls of the test room than 1,64 ft (0,5 m) from the floor. This excludes the area which is within 3,9ft (1,2 m) from the corner where the ignition source is located.
6. No flaming drops or debris of the test sample may reach the floor of the test room except the area, which is within 3,9 ft (1,2 m) from the corner where the ignition source is located.
7. There should be no flash over.

Fire Resistance:

It describes the ability of a construction / division to prevent a fully developed fire spreading from one compartment to a neighbor compartment within a specified time. Fire resistance properties includes fire insulation, flame and smoke tightness, and structural capacity and integrity. Tests that determine these types of properties are tests on constructions. These tests are designed to represent a realistic full-scale fire division.

Fire Resistance Test:

In HSC`s fire resisting divisions are classified by stating the minimum time for smoke and flame integrity, and temperature rise of average 284°F (140°C) at the unexposed side. In addition it must be stated if the division is load bearing or not. Materials in the construction must be non-combustible or the division, as a whole, must be classified as a "Fire Restricting Material". A "60 min load bearing deck" test is equivalent in function to a SOLAS class "A-60" deck, while a "60 min non load bearing bulkhead" does not have any SOLAS equivalent.

The criteria are fulfilled when: The average unexposed face temperature rise is below 284°F (140°C), and the temperature rise recorded by any of the individual unexposed face thermocouples does not exceed 356°F (180°C). There should be no flaming on the unexposed face and there should be no flaming or glowing of a cotton wool test pad held at a distance of approximately 1" (25 mm) from any point of the test specimen for a period of 30 sec. It should not be possible to enter the gab gauges into any opening in the specimen. Performance criteria for load bearing ability: Limiting deflection of $L/15,7$ " (400 mm) d and Limiting rate of deflection of $L/354$ " /min (9000 mm/min) d

Were: L= the clear span of the specimen

d= the distance from the extreme fiber of the design compression zone to the extreme fiber of the design tension zone of the structural section.

Material Properties Of PMI Foams [4]

Table 1 shows the property profile of PMI foams. Compared to any other foam core material, PMI foams offer a superior strength-to-weight ratio. Table 2 and 3 show the specific tensile strength / specific modulus of elasticity / specific shear strength and modulus of some foam plastics and it becomes obvious that the properties of PMI surpass those of any other foam core materials. Taking these results into account, PMI foams enable the manufacture of structures with maximum weight optimization.

If one compares the dynamic shear modulus versus temperature behavior, another advantage of PMI foams can be pointed out. As a conclusion from Table 4, it can be stated that only PMI foams offer a suitable level of mechanical properties at temperatures of 176°F (80°C) and higher. This is of relevance to marine vessels painted in dark colors, superstructure and main deck exposed to extreme sunlight, structures exposed to engine heat or in general, in the event of fire. A PVC foam, for example, shows a significant drop in mechanical property levels at approximately 167°F (75°C) already. This has to be considered as a potential risk in the design considerations.

If we evaluate the fire behavior of a sandwich foam core when skins are burned through, the amount of smoke and the toxicity of the fumes produced by the foam is a point of major interest. Table 5 shows the smoke density of some foams determined according to Airbus fire and safety regulations. PMI foams burn without releasing any corrosive or toxic emissions.

Owing to their chemical nature, PMI foams absorb moisture from the environment similar to any other polymer. At room temperature/50% rel. humidity they saturate at 3.5% moisture content. This is a pure diffusion process which is reversible by drying. Because of this fact, PMI foams only received a DNV approval for applications above the water line. Balsa core however absorbs much higher amounts of moisture and even rots away, but received a specification for underwaterline application due to its wide use in the past.

In sandwich constructions, the foam core is always covered by skins and thus only directly exposed to water in case of a damage. A long-term test (40 months) with simulated skin damage shows how PMI foam behaves under direct water exposure. Table 6 shows that the moisture content 6" (150 mm) away from the damaged area is zero and has no influence on the PMI foam core.

The full cored PMI surface effect ship Corsair was taken out of service in 1999. A piece of the keel section which was exposed more than 13 years to high dynamical loads and shock loads under the water line was examined. The sample showed no change in mechanical properties and only little moisture pick up of 2,5%.

The fatigue behavior of PMI cores were examined at the Technical University of Stockholm in Sweden. The performed test series showed that PMI foams can be loaded up to 58% of their static fracture load, when dynamically loaded up to 5 million cycles.

Test Program To Reach The HSC Code [1]

The test program was initialized by Röhm GmbH & Co.KG in cooperation with FiReCo AS Norway. The project "Qualification of ROHACELL[®] for application in the marine market" started in 1999.

The program covers:

- I. Basic evaluation of a number of proposed constructions with different core materials and fire protections by Cone Calorimeter Tests
- II. small scale furnace tests of promising candidates from phase 1
- III. full scale fire reaction test (room corner) and full-scale furnace test

Phase I

In the first part plain core materials were tested. The influence of the core is significant. In the second part a typical sandwich construction with GRP and vinyl ester was tested. The influence of the core is still important but the values for Tig (Time to ignition), HRR (heat release rate), THR (total heat release), SPR (smoke production rate) come closer together. The HSC can't be fulfilled. In the third part the sandwich was covered with a suitable insulative layer. The influence of the core material becomes secondary, except the structural integrity at elevated temperatures. Table 7 shows the test results from the basic evaluations of different core materials.

Phase II

Promising candidates from Phase 1 were tested in a small scale room corner test. Mainly different furniture, thickness of the isolative layer and materials were tested to find a weight and cost optimized solution.

Phase III

The weight and material optimized construction was tested under the ISO 9705 “room corner test”. The construction is shown in figure 3. It exists of a typical design which is used in marine applications. A ROHACELL[®] 71 IG (4,43 pound/ft³) core with GRP multiaxial layer and polyester was chosen. X-Fireliner FPG-MKII 0,5/12,7 was used as an insulative layer. The mounting of the insulative panels was realized with steel profiles screwed to the sandwich. In figure 2 the values for the HRR and the smoke production are illustrated. Both meet the regulations of the ISO 9705. **The weight of the interior finish/protection panel including insulation is only 7,3 lb (3,3 kg/m²).**

A “Load bearing fire resisting deck 60” test was performed. The construction is shown in figure 4. It shows a typical design which is used in marine applications. A ROHACELL[®] 71 IG (4,43 pound/ft³) core with a multiaxial glass layer and polyester was chosen. The Firemaster X-607 insulation was used. Figure 5 shows the temperature at the unexposed side. Figure 6 shows the deformation of the construction. The regulations of the “Load bearing fire resisting deck 60” test are fulfilled **The weight of the insulation is only 15,4 lb (7 kg/m²).** **The weight for the “Load bearing fire resisting deck 30” is only 9,3 lb (4,2 kg/m²).**

Conclusion

PMI foams have proven to be highly suitable for applications in the marine industry. A comparison of their specific mechanical properties with those of other core materials shows, that the benefits of weight savings and superior behavior at high temperatures / high loads allow to realize improved lightweight ship structures such as e.g. superstructure and car decks.

The fatigue behavior of PMI cored sandwich constructions showed excellent results in laboratory and real-world test programs.

In marine vessel constructions, a proven system which meets the requirements of the IMO HSC offers new opportunities for significant lightweight designs to naval engineers and shipyards.

Taking all these benefits into account, PMI foams provide an alternative to conventional core materials used in the marine industry.

References

[1] Qualification of ROHACELL[®] for application in the marine market – FiReCo Norway 2000

[2] FIRE PTECTION OF COMPOSITE VESSELS: FIRE PROTECTION AND STRUCTURAL INTEGRITY – AND INTEGRATED APPROACH - Fast ferry `97 FiReCo AS Norway

[3] IMO Resolution MSC.45(65), MSC.40(64), MSC.90(71)

[4] Property Profile ROHACELL[®] - Röhm GmbH & Co.KG

ROHACELL Property Profile

Poly-Methacryl-Imid Foam

- free from CFC's, halogenes and bromine
- ease of machining, no special tooling required
- them oform ability
- 100 % closed cell structure
- compatibility to any matrix system (wet and prepreg)
- high heat distortion temperature, 180°C - 250°C (350°F -420°F)
- outstanding strength-to-weight ratio
- outstanding creep compression resistance
- good dielectric properties
- classified to be non-toxic acc. to AITM and
- low smoke density acc. to AITM and
- no release of corrosive emissions when burning
- them al recycling

Table 1: Property Profile of PMI foams

Specific Tensile Strength / E-Modulus

(density = 80 kg/m³ / room temperature)

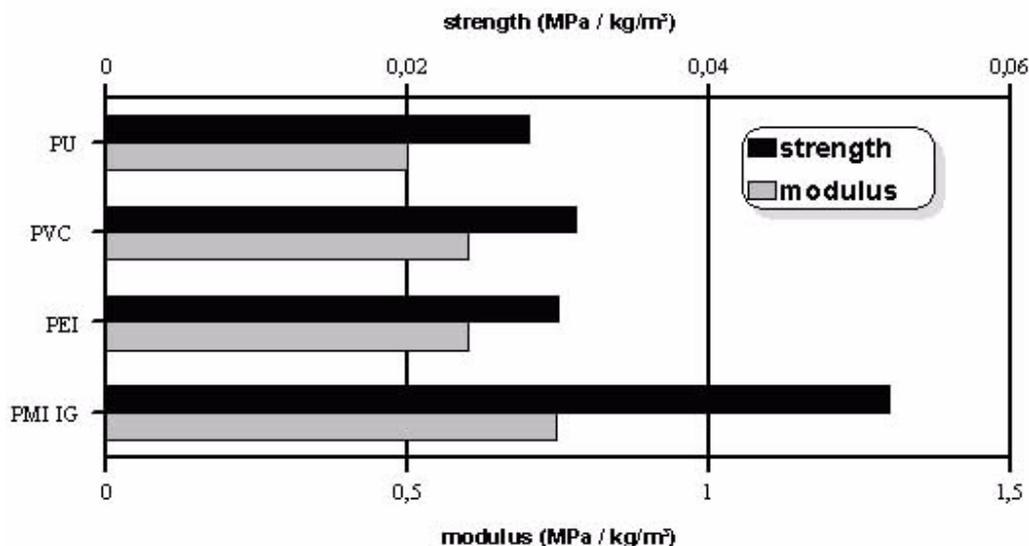


Table2: specific tensile strength / modulus

Specific Shear Strength / Shear Modulus

(density = 80 kg/m³ / room temperature)

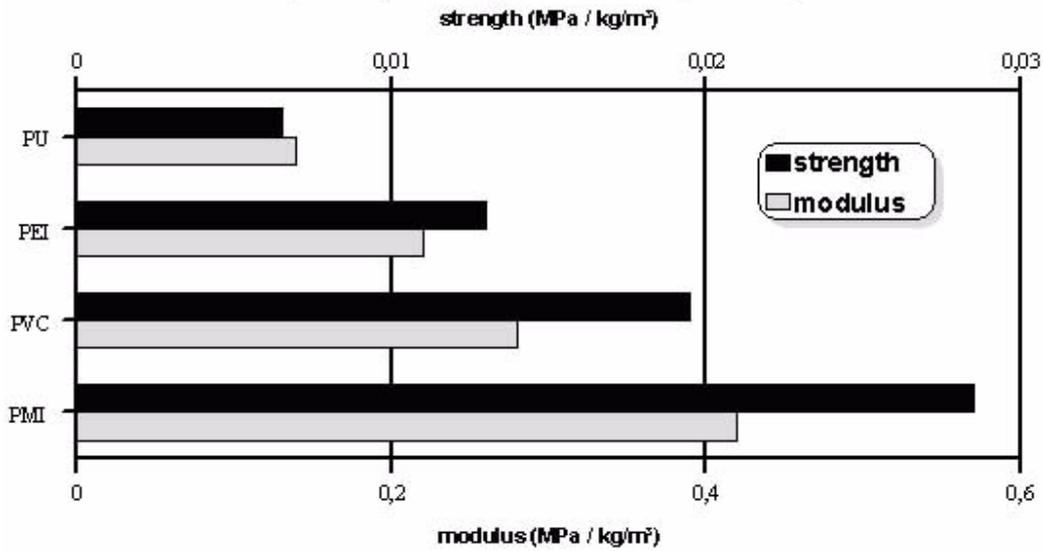


Table 3: specific shear strength / modulus

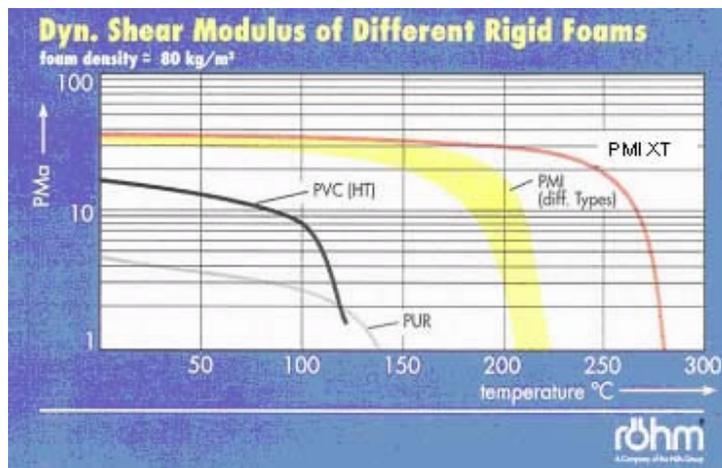


Table 4: dynamical shear strength vs. temperature

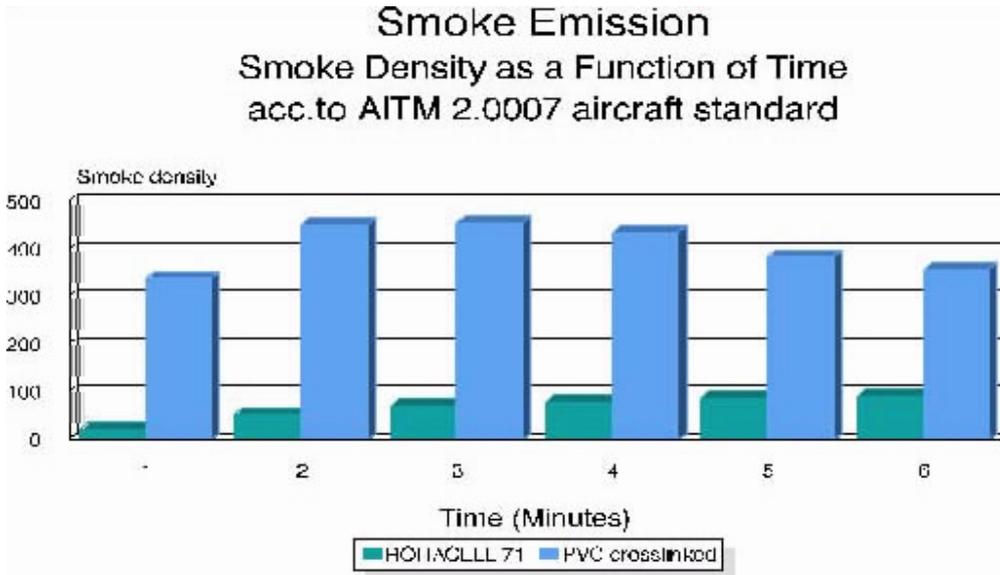


Table 5: Smoke production

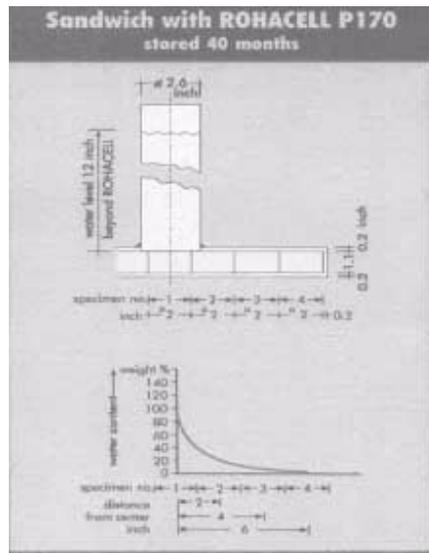


Table 6: water absorption after storage

ID	Tig (s)	Peak HRR (kW/m ²)	Total HR (MJ/m ²)	Average SPR (m ² /s)	Estimated time to Flash-over (s)
<i>Plain cores:</i>					
R1-PMI-71IG	7	645	51.2	0.0269	26
R2-PVC-H80	47	174	16.5	0.0804	158
R3-Balsa-D57	4	130	45.0	0.0008	32
R4-PEI-R82-80	82	161	21.5	0.0154	244
<i>Cores + polyester lam. (sandwich)</i>					
R5-POLY/PVC	33	422	156.5	0.0559	65
R6-POLY/PMI	31	412	148.2	0.0416	61
R7-POLY/Balsa	38	369	64.3	0.0123	83
<i>PMI/poly. sandwich + protection</i>					
R8-FRM-FiReLiner 12 (2.65 kg/m ²)	16	28	3.4	0.0011	643-No flashover **

Table 7: Cone Calorimeter Test results

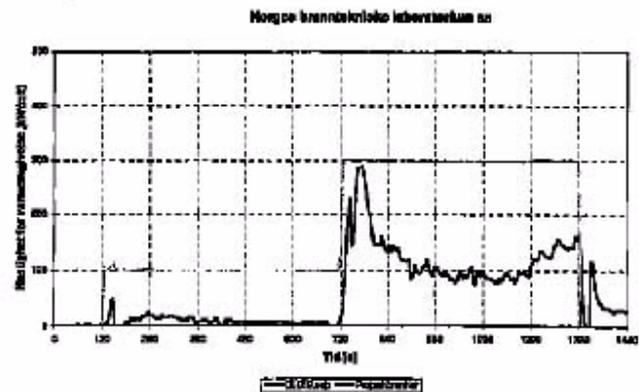


Figure 1 Heat release rate as a function of time for both the product (01019.exp) and the propane burner.

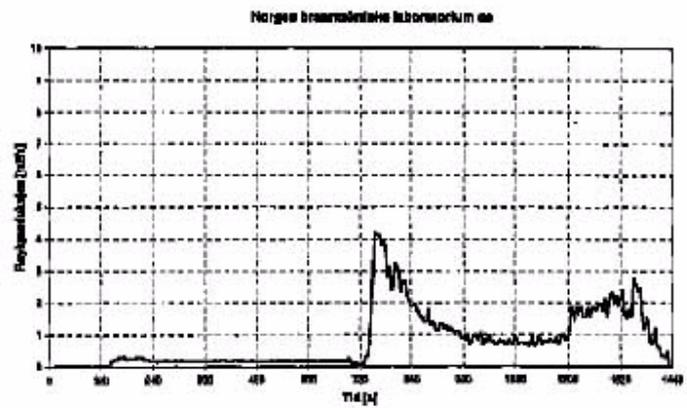


Figure 2 Smoke production as a function of time [m^3/s]

Further details regarding the performance of test and test results will be found in test report no. 102010.80/01.019, dated 2001-03-19.

Figure 2: ISO 9705 Heat release and smoke production

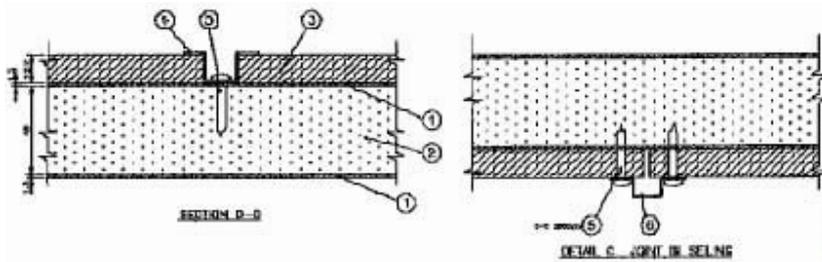
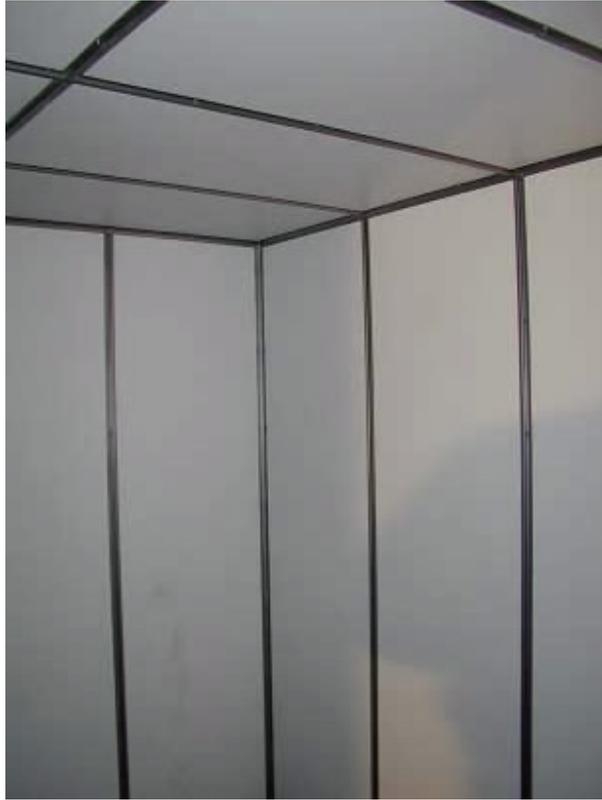


Figure 3: ISO 9705 construction of room corner test

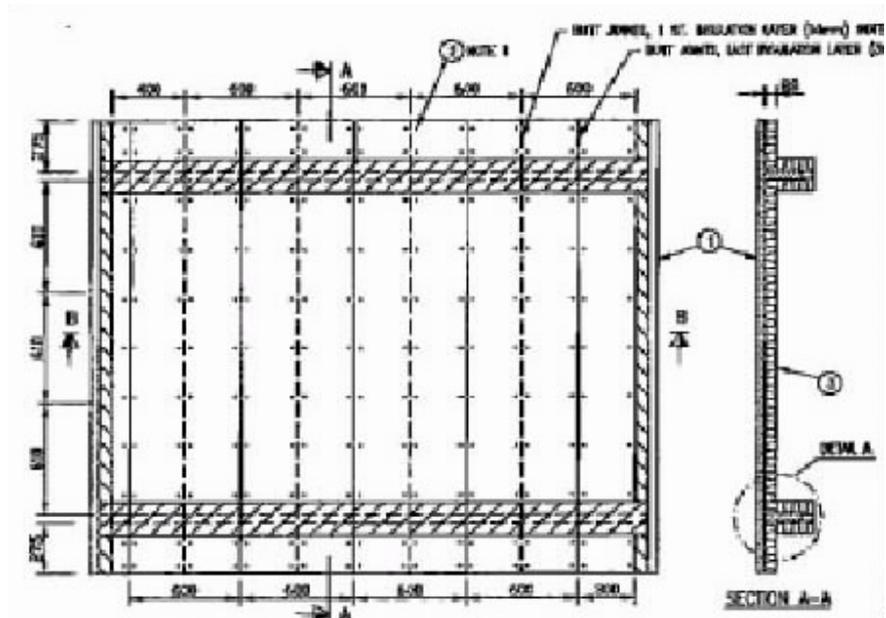


Figure 4: Construction of deck test

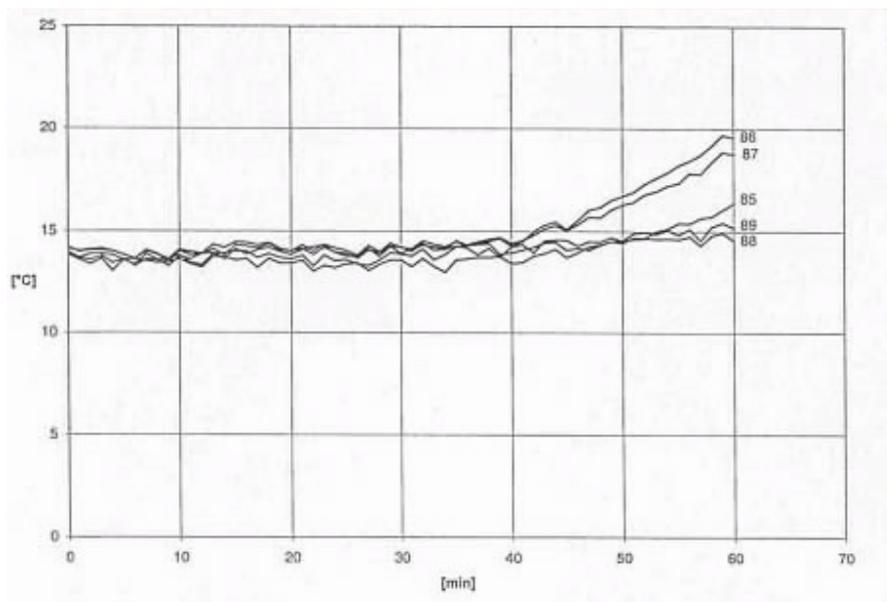


Figure 5: deformation of the construction