Maritime & Coastguard Agency

MARINE GUIDANCE NOTE

MGN 407 (M+F)

Procedure for the Testing of Fire Protection for use with Composite and Wooden Constructions

Notice to all Owners and Operators of Ships, Ship Builders, Designers and Surveyors

Summary

Advances in technology and the now prolific use of composites in the yacht and small ship building industries indicate that guidance is required for the testing of fire protection of composite structures. Guidance for fire testing has historically been applicable only to steel or steel equivalent materials.

This Note details the research undertaken and the procedures to be followed to demonstrate the fire protection standards for non-steel constructions. It is intended that the fire test will be undertaken for the worst case construction used in the design to avoid the need for multiple fire test configurations.

1. Introduction

The introduction of EU Directive 98/18/EC on standards for passenger ships on domestic voyages, recast as 2009/45/EC, highlighted a problem that the Directive is applicable only to ships constructed of steel or equivalent materials (e.g Aluminium). This resulted in a disparity in standards as non-steel or equivalent ships continue to be built in accordance with existing UK Class VI legislation. The MCA wish to apply the standards of the Directive to all passenger ships, regardless of material of construction, standards therefore it was necessary to develop procedures to allow composite vessels to meet the for fire protection of the Directive. The findings of the research need not be limited to passenger ships. The procedures developed may be applied to any ship type built of composites where fire protection is required. Similarly, the research addressing the fire protection of composites focused on GRP constructions, however, the procedures developed will equally be applicable to other fibre types used to reinforce plastics.

The MCA has undertaken research to develop procedures that can be followed to demonstrate the fire protection standards for non-steel constructions. An objective of the programme was to identify the construction that represents the worst case used in the design so that fire protection need be tested only on the worst case construction in the same way as is done for Steel and Aluminium constructions, eliminating the need for multiple fire test configurations for individual ships. It has been necessary to establish what attributes of each wooden or composite construction represent the worst case scenario. The research has considered the most commonly used construction materials and investigated the relevant attributes that may be varied to identify the worst case for each construction material.

A metallic bulkhead conducts heat very well, and the main reason for the fitting of structural fire protection is to stop the spread of fire from one compartment to the next. It is worth remembering that (aluminium aside) the survival of the structure is not of primary concern.
However, where wood and composites are concerned, the opposite is true. In this case, the structure is an insulator. The downside of these materials is that they have relatively poor structural response to heat. It is for this reason that insulation is required to be fitted to these structures. So in effect, we are not concerned with spread of fire through conduction, more with the collapse of the structure.
In this regard, assuming that the structure has been sufficiently protected to ensure no collapse we are then interested to know what represents a 'worst case' thermally for the bulkhead.

This guidance can be used by ship owners, operators and designers to identify which fire tests will need to be undertaken to demonstrate the construction is sufficiently insulated to meet the fire protection standards required by regulation.

The fire testing will involve testing the worst case construction with the selected insulation. The testing should be performed in an indicative size furnace (1200 x 1200mm or larger) to the ISO 834-1 standard and should use the standard heating curve specified by this standard. The results need to demonstrate that the absolute temperature (not temperature rise) measured on the exposed face of the construction material is below the specified maximum for the specific material at the end of the fire test. In the case of composites, this temperature will be Heat Deflection Temperature (HDT) and in the case of wooden constructions, a temperature below onset of charring. Once an individual construction and insulation combination has been demonstrated to satisfy the requirements, this construction or a less onerous variant can be used in the intended design without the need for further testing.

2. Summary of Fire Test Results

Full details of the fire testing research and results are given in Annex 1. A brief summary of the findings for each construction material is given in this section

2.1 Plywood and Wooden Constructions

The tests indicated that the thickest plywood construction was the most onerous case. Therefore the thickest plywood with the selected insulation should be tested. Provided the plywood and insulation combination has been approved through the fire testing process, a thinner plywood construction with the same insulation would also be approved on the basis that the worst case thickness had been approved.

The criteria for fire tests on plywood constructions is that the absolute temperature on the fireside remains below 200°C and on the **non fireside** a temperature rise from ambient of 140°C average and a rise above ambient of no more than 180°C at any individual point for the full duration of the appropriate fire test exposure.

2.2 Monolithic Glass Reinforced Plastic (GRP) Constructions

The tests indicated that the thickest monolithic GRP construction was the most onerous case. Therefore the thickest monolithic GRP with the selected insulation should be tested. Provided the monolithic GRP and insulation combination has been approved through the fire testing process, a thinner monolithic GRP construction with the same insulation would also be approved on the basis that the worst case thickness had been approved. It is also possible to approve the same structure on the basis of a greater HDT which shall be measured to ISO 75 (Plastics — Determination of temperature of deflection under load).

The criteria for a fire test on monolithic GRP construction is that the temperature on both fire-side and non-fire-side remains below the HDT.

2.3 Cored GRP Constructions

There are three variables which need to be considered when testing cored GRP constructions: skin thickness, core thickness and core density.

The criteria for fire tests on cored GRP constructions is that the temperature on both fire-side and non-fire-side remains below the lowest of the Heat Deflection Temperatures (HDT) for the composite construction which shall be measured to ISO 75.

It is known that the structural properties of commonly available PVC Cores are reduced with exposure to heat and some attention has been paid to assess the temperatures to which the cores are being exposed. Currently there is no acceptable method to establish an 'HDT' for PVC Foam cores that would relate in some way to the HDT that is used to assess resins. Given this, and taking into account the results of tests where the temperature between the exposed face skin and the core has been measured it should not be necessary to introduce any further failure criteria. The exposed face skin does much to protect the core. As with Monolithic GRP structures, the lowest HDT represents a 'worst case', therefore the same structure with a higher HDT could be accepted without further testing.

2.3.1 Skin Thickness

The tests indicated that the construction with the thinnest skin was the most onerous case. Therefore the construction with the thinnest skin with the selected insulation should be tested. Provided the tested combination has been approved through the fire testing process, a construction with a thicker skin with the same insulation would also be approved provided that the other parameters such as core thickness and density remain unchanged.

2.3.2 Core Thickness

The tests indicated that the construction with the thickest core was the most onerous case. Therefore the construction with the thickest core with the selected insulation should be tested. Provided the tested combination has been approved through the fire testing process, a construction with a thinner core with the same insulation would also be approved provided that the other parameters such as skin thickness and core density remain unchanged.

2.3.3 Core Density

The tests indicated that the construction with the least dense core was the most onerous case. Therefore the construction with the least dense core with the selected insulation should be tested. Provided the tested combination has been approved through the fire testing process, a construction with a denser core with the same insulation would also be approved provided that the other parameters such as skin thickness and core thickness remain unchanged.

3. Procedures for Fire Testing

3.1 Required Fire Tests

It will be necessary to identify which constructional components will need to be included in the fire testing for a proposed ship design. Based on the findings summarised in section 2, fire tests will need to be undertaken for the worst case for each construction material, noting that all other variables will remain unchanged. This means that the insulation, fixing arrangements, materials and lay-up used in the ship must be consistent with that used in the fire testing. Approvals should only be sought for systems tested on the same materials, the materials must be the same as those which have been tested, ie. A product tested on a PVC Cored construction can only then be extrapolated for use on other PVC Cored constructions.

The tests shall be performed on the following constructions for the worst case, as given in the following table. Whilst the research addressing the fire protection of composites focused on GRP constructions, the procedures developed will equally be applicable to other fibre types used to reinforce plastics.

Material	Variant	Testing requirement
Plywood	Thickness	The thickest construction shall be tested
Monolithic GRP	Thickness	The thickest construction shall be tested
Cored GRP	Skin thickness	The thinnest skin shall be tested
Cored GRP	Core thickness	The thickest core shall be tested
Cored GRP	Core density	The least dense core shall be tested

3.2 Test Procedure

The fire tests should be performed in indicative size test furnaces of 1m x 1m or more, capable of generating the standard time/ temperature curve specified in ISO 834-1. The test panels shall be of same size as the indicative furnace in which they are being tested.

The fire tests durations shall be 60 minutes for A Class equivalent boundaries and 30 minutes for B Class equivalent boundaries.
No less than five thermocouples shall be used on the exposed face of the structure and these shall be placed on the exposed face of the wood or composite structure. This is the interface between the fire protection medium and the structure that it protects. At least one thermocouple must be placed on the unexposed face of the structure.

3.3 Compliance Criteria

The temperature measures both on the fire side and non-fire side of the construction material must remain within the limits specified for the full duration of the fire test.

Material	Compliance Criteria
Plywood	Temperature remains below 140°C
Monolithic GRP	Temperature remains below the HDT of the GRP
Cored GRP	Temperature remains below the HDT of the GRP
Cored GRP	Temperature remains below the HDT of the GRP
Cored GRP	Temperature remains below the HDT of the GRP

3.4 Fixings

The fixings used to fix the insulation onto the construction material in the fire test shall be the same as method intended for use in the ship itself. Due consideration should be given when choosing the method and type of fixing and it will be necessary to take into account the maximum permissible operating temperature of the fixing method. It should be noted that metallic fasteners transmit heat readily and this will have an impact on both the structure and the medium used to fix the metallic fastener onto the structure.

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Annex 1 – Research Programme

1. Introduction

IMO Resolution A.754(18), The International Code for Application of Fire Test Procedures includes guidance related to the testing of steel and aluminium structures and sets out the procedures which should be followed in order to meet the fire safety standards for A Class divisions. The A class standard terminology is commonly used in both international and national legislation. The procedure within the resolution is not appropriate for tests on composite structures, therefore an alternative equivalent standard is needed to be developed with test procedures for insulated composite structures.

Currently there is no true equivalent to the A Class standard for 'steel or equivalent' structures ('equivalent' in this context means materials such as aluminium which can be tested under the same procedures) that can be applied to fire protection for non steel structures. The current standards used by the MCA for the purpose of approving the structural fire integrity of composites in small vessels are basic and do not adequately address all the potential problems experienced by composites in a fire. The current guidance is prescriptive and does not allow for innovation and technological advances. This guidance is contained in non-statutory documents and therefore, no legal provision for insulation standards applicable to non-steel structures exists.

The MCA research was undertaken to develop a testing methodology to demonstrate that the insulation applied to a non-steel structure is at least equivalent to the insulation standards as applied to steel structures. The A Class Standard terminology will continue to be used and this guidance explains how the equivalent standard can be applied to a non-steel structure to demonstrate the A Class standard has been satisfied. The research programme involved testing a range of composite and wooden structures with insulation applied. A de-coupled testing procedure was applied to insulation materials and structural components. This was designed to guarantee safety taking whilst taking account of real-world manufacturing tolerances and to remove any undue testing burden from the small boat building industry.

The research programme considered both GRP and wooden constructions. Of these two types of construction, GRP structures are considered to be a higher risk in the event of fire. This is due to the comparatively low temperature at which the resin component of a composite loses strength and starts to soften (commonly referred to as the Heat Deflection Temperature (HDT)). For the most popular composite resin, polyester, this is usually in the region of 50–80°C. Wooden structures tend to remain structurally sound even after the onset of charring.

It is possible and reasonably practicable to insulate both composites and wood to a standard of fire resistance equivalent to A60 (currently the most stringent standard recognised in the marine industry). This is regularly achieved by the large yacht industry, although at considerable cost. Much of the cost of insulating non-steel vessels is in the testing of each individual construction.

A method has been devised for the testing and approval of various insulation types and specifications in order that individual constructions need not be tested. Essentially a sort of 'off the shelf' insulation package will be available for various constructions rather than needing a bespoke custom designed and tested system which becomes very costly.

The research involved undertaking a series of fire tests with different construction materials to determine how the materials behaved when attributes such as the thickness and density of the structure were varied. Composites are insulators rather than conductors, therefore the structure itself insulates the cold face and slows down the rate of heat transfer through the material. The relationship between the skin thickness, core thickness and core density were all investigated in the research programme, with the temperature of the exposed face beneath the insulation being recorded. The results demonstrate how the exposed face temperature varies for each material tested as certain attributes are changed. This has allowed us to identify the 'worse case' for a particular material or composite lay up.

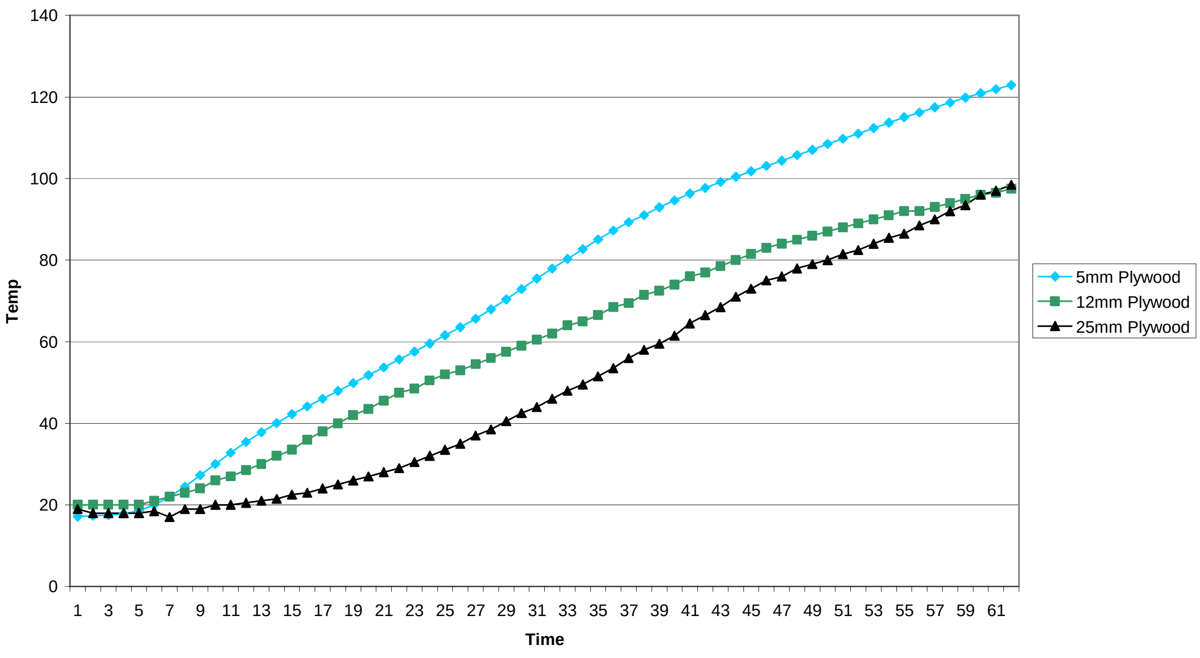
Throughout the tests, the test samples were subjected to the standard temperature curve as specified in ISO 834-1 which is referenced in the IMO FTP code – Part 3 (IMO Res A.754(18)). The findings of the individual tests and conclusions drawn are described in the following section.

2. Results and Conclusions

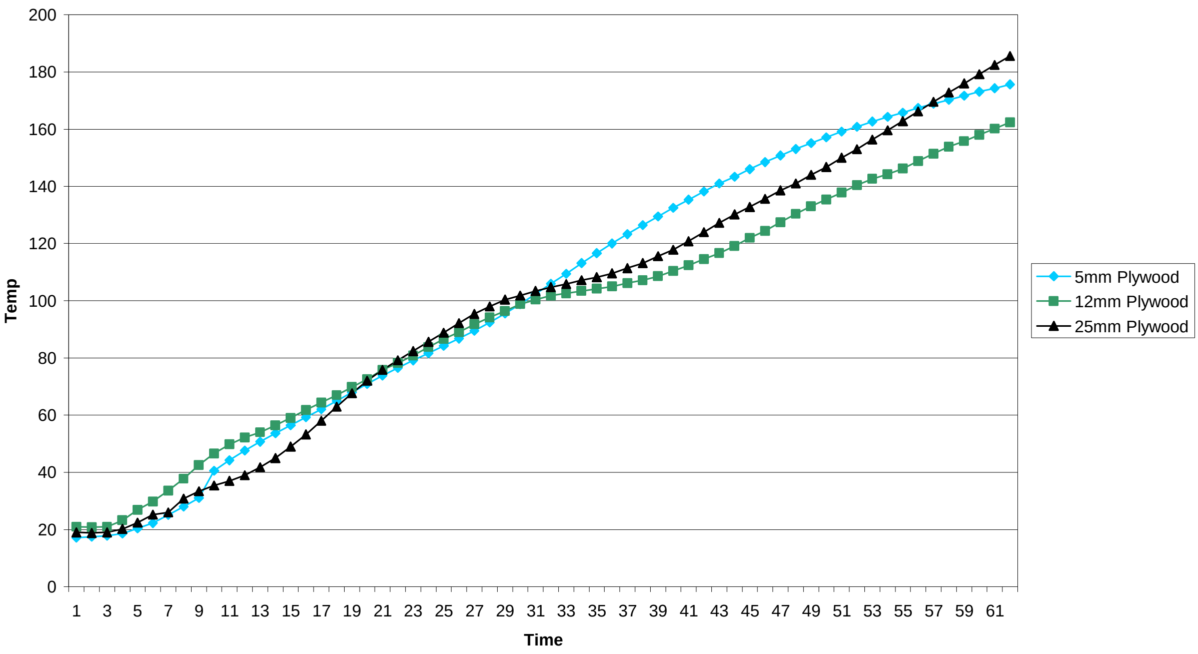
2.1 Plywood

The tests undertaken with plywood generally appear to support the theory that a thicker panel will produce a higher temperature on the exposed face. It is understood that the thermal resistance (r) of plywood increases with thickness. It can be seen from graphs showing unexposed face temperatures (Graph 1) and exposed face temperatures (Graph 2) that the 5mm and 12mm panels allow heat to permeate through the panel to the cold (or unexposed) face much more efficiently than the 25mm panel. The temperature at the cold face of the 5mm and 12mm panel is almost continually hotter than that of the 25mm panel, thus demonstrating that the thicker panel has higher thermal resistance and lower thermal conductivity.

Graph 1 - Unexposed face temperatures for Plywood - 1500 x 1500mm test

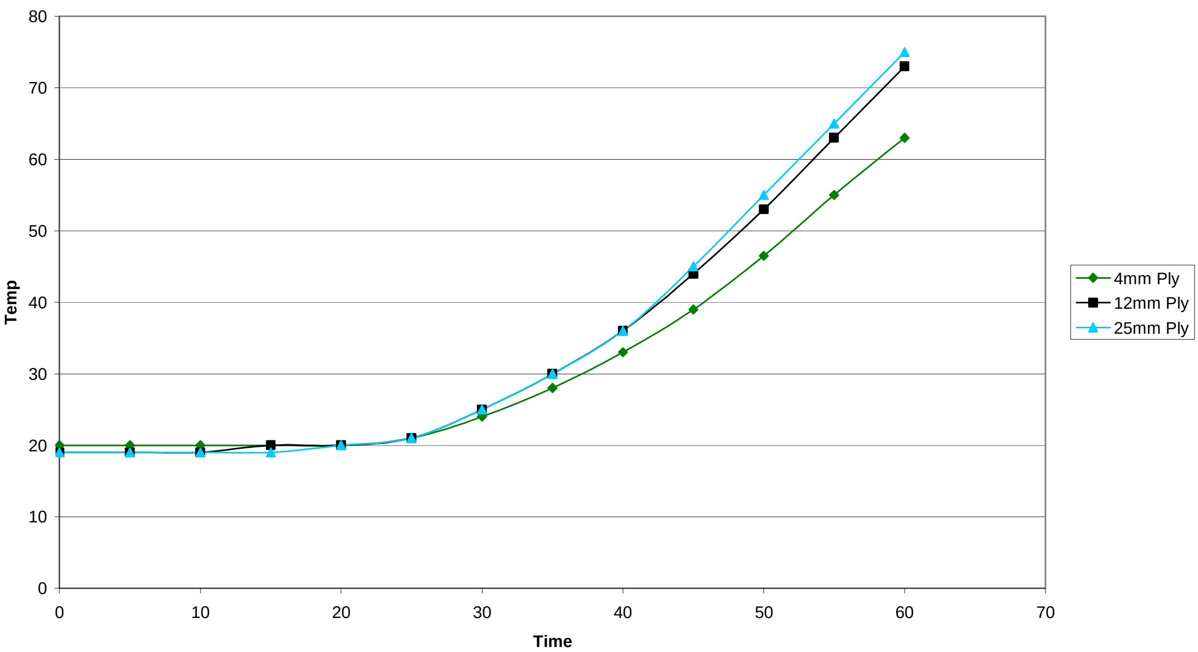


Graph 2 - Temperature on exposed face of Plywood Vs. Thickness (1500 x 1500mm)



There is a slight anomaly in the results in Graph 2 where the exposed face temperature of the 5mm panel rises more rapidly at temperatures above 100°C than both the 12 and 25mm panels. There are two possible explanations for this, either it is due to the effect of the 'volume' of the panels, where the 5mm panel has become saturated with heat more quickly, or it may due to the amount of water embodied in the panel, which may begin to 'boil off' at around 100°C. The smaller panel would effectively 'dry out' much faster and then the temperature would begin to rise again. Moisture content was not measured before, during or after testing. The 5mm ply was included in the research to provide 3 different thicknesses of plywood to demonstrate the trends as thickness is varied. A 5mm plywood thickness would not be used in practice and we are content that it is appropriate to base the conclusions on the results of the 12 and 25mm panels.

Graph 3 - Plywood Thickness Vs. Exposed Face Temp (440mm x 440mm)



Graph 3 shows the results for some small scale tests which support the theory that due to properties of conductivity and thermal resistance (r), the exposed face temperatures are higher for thicker panels.

It is necessary to define the point at which the plywood panel would be deemed to fail a fire test. Plywood reacts to elevated temperatures by charring. This process results in weight loss which would eventually lead to a severe reduction in structural properties through diminution. The temperature at which wood chars varies from species to species and is dependant on the density and moisture content. Some research has been conducted on this, and it appears that a temperature of between 280 and 300°C is accepted as the temperature for the onset of charring (for a short period of exposure).

From these tests it has been possible to prove that plywood can easily withstand temperatures up to 140 – 180°C as specified in Res. A.754(18) without significant damage.

Therefore the failure criteria for the testing of wooden constructions will be the average temperature at the exposed face exceeding 140°C or a localised temperature exceeding a 180°C at any point on the exposed face.

2.2 PVC Cored GRP

PVC Cored GRP is likely to be one the most popular and desirable forms of construction, both presently and into the future. The reasons for this are the cost, usability and in-service properties of the materials. PVC core is a relatively cost effective material that results in a light and stiff structure.

One disadvantage of PVC cored GRP is the relatively poor structural response under elevated temperatures. The most commonly used variety of PVC foam core within the boatbuilding industry is AIREX C70 which demonstrates a reduction in shear strength of approximately 80% when exposed to temperatures of 90°C.

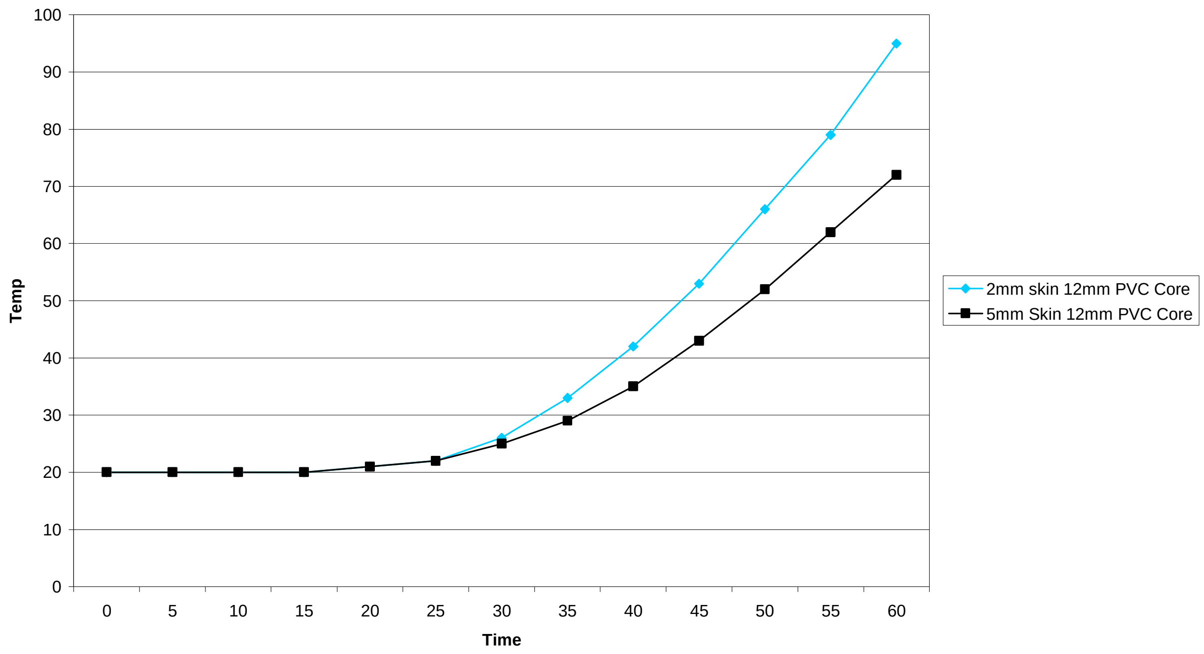
There are alternative PVC cores available that have improved structural response with heat but these tend to be more expensive and are not widely used in the boatbuilding industry currently.

2.2.1 Effect of Thickness of GRP Skins

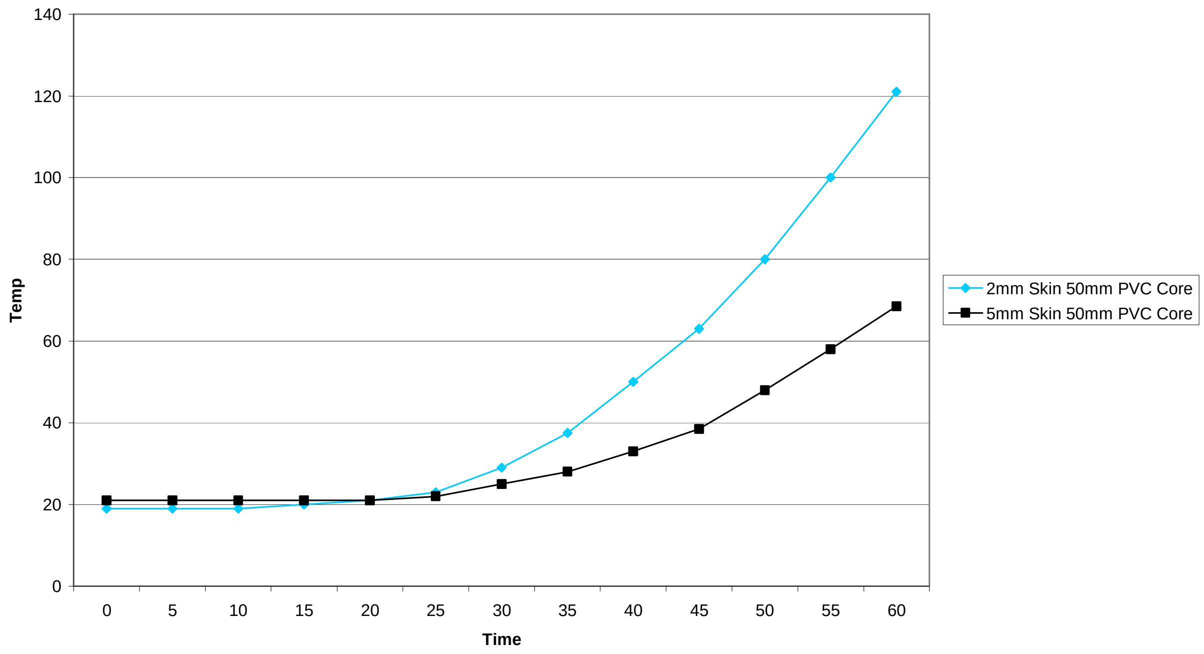
In order to identify the effect of skin thickness on a PVC Cored construction we tested 4 panels;

1. 2mm skin on 12mm core
2. 5mm skin on 12mm core
3. 2mm skin on 50mm core
4. 5mm skin on 50mm core.

Graph 4 - Exposed face temperature with variation in skin thickness with PVC Core



Graph 5 - Exposed face temperature with variation in skin thickness with 50mm PVC Core

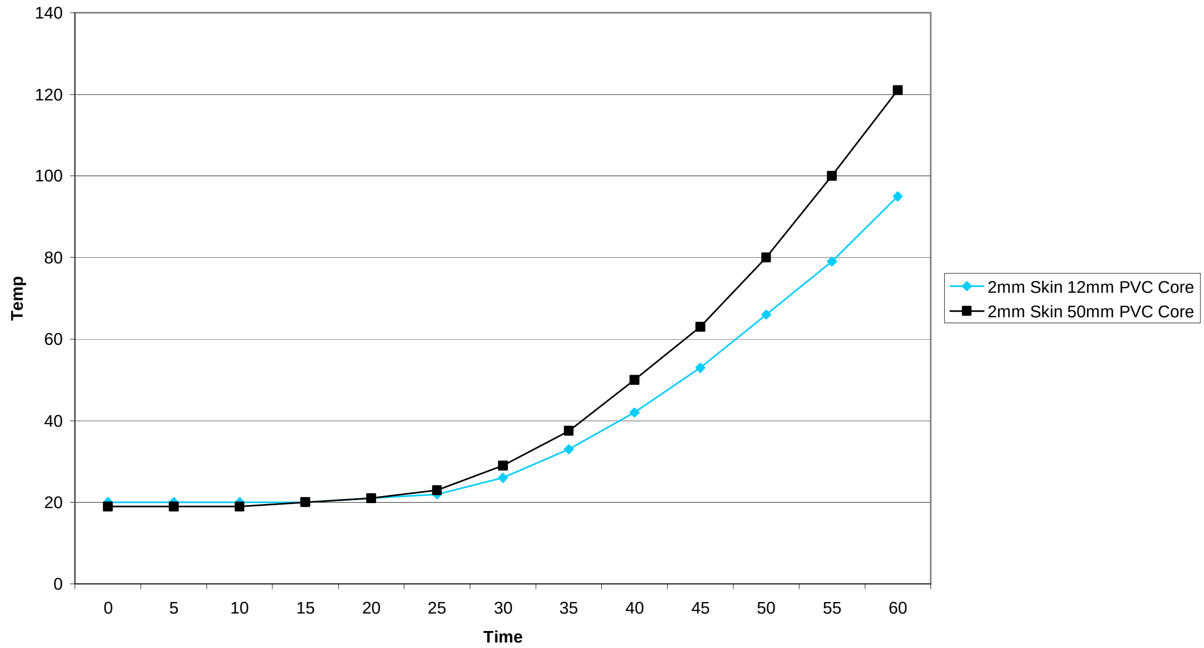


Both graphs show that the exposed face temperature is increased when the thickness of the skin is reduced. Therefore when testing PVC cored panels, assuming that the core remains the same thickness and density, the construction with the thinnest exposed face skin should be tested.

2.2.2 *Thickness of PVC Core*

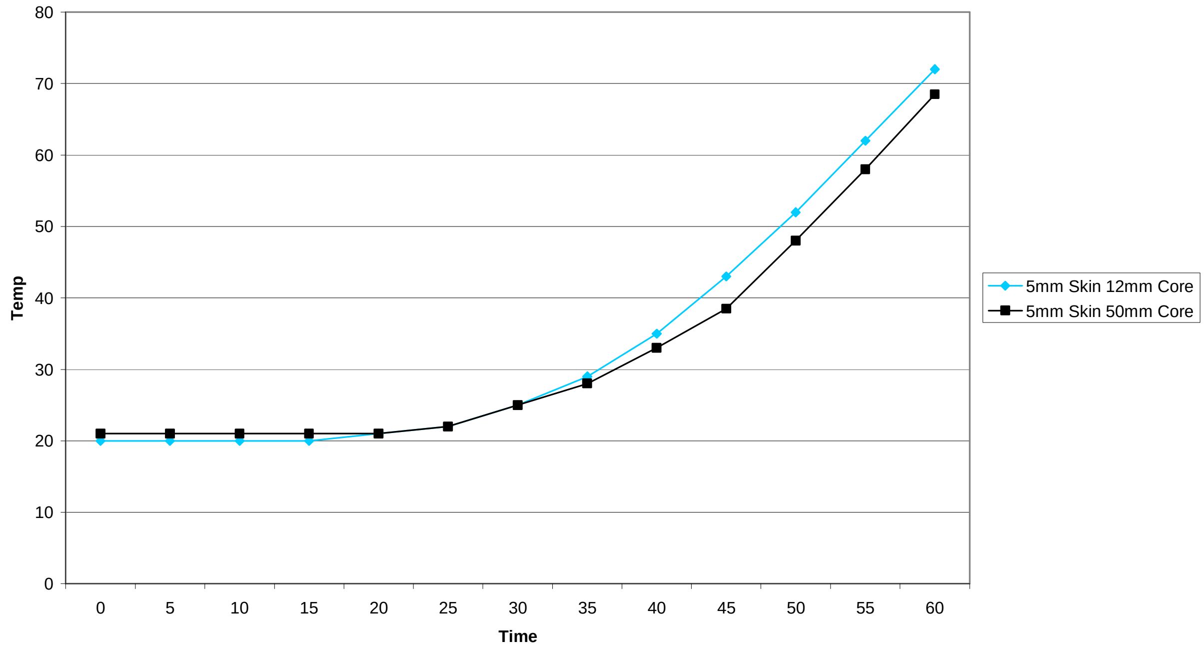
Using the same data, graph 6 shows that when thin skins are used (as is typical with PVC cored construction) and the thickness of PVC core is altered, the exposed face temperature increases with increased core thickness.

Graph 6 - Exposed face temperature with variation in core thickness



Graph 7 is intended to show the effect of core thickness when thicker GRP skins are used. This is inconclusive as it appears that heat remains within the skin and there is little difference between the exposed face temperatures for the different core thicknesses. The combination of thick skins and a thick PVC core would be unlikely to be used in construction as the reason for the use of a core is to increase stiffness whilst reducing weight.

Graph 7 - Exposed face temperature with variation in core thickness (5mm skins)



Using the results of graph 6, the exposed face temperature is higher with a thicker core, therefore the thickest core should be tested. This assumes that the PVC core density and skin thickness remain unchanged.

With regard to the failure criteria, the overall HDT of the structure will be higher than that of the constituent parts. Therefore, although the PVC Core may well have an HDT lower than that of the GRP, we will use the HDT of the GRP as the failure criteria.

2.3 Balsa Cored GRP Constructions

Balsa core is less susceptible to heat than PVC cores. In the same way that plywood actually has good resistance to heat and also retains much of its structural properties at moderately elevated temperatures, so does balsa.

In the tests, the balsa remained unaffected by the exposure to heat. The only evidence of heating was slight discoloration of the exposed GRP caused by heating.

It is therefore safe to assume that the balsa core has far greater resistance to heat than the GRP with which it would be faced. For this reason we need not be overly concerned with the limiting temperature of the balsa core but with that of the failure of GRP skins.

2.3.1 *Effect of Skin Thickness of Balsa Cored GRP Constructions*

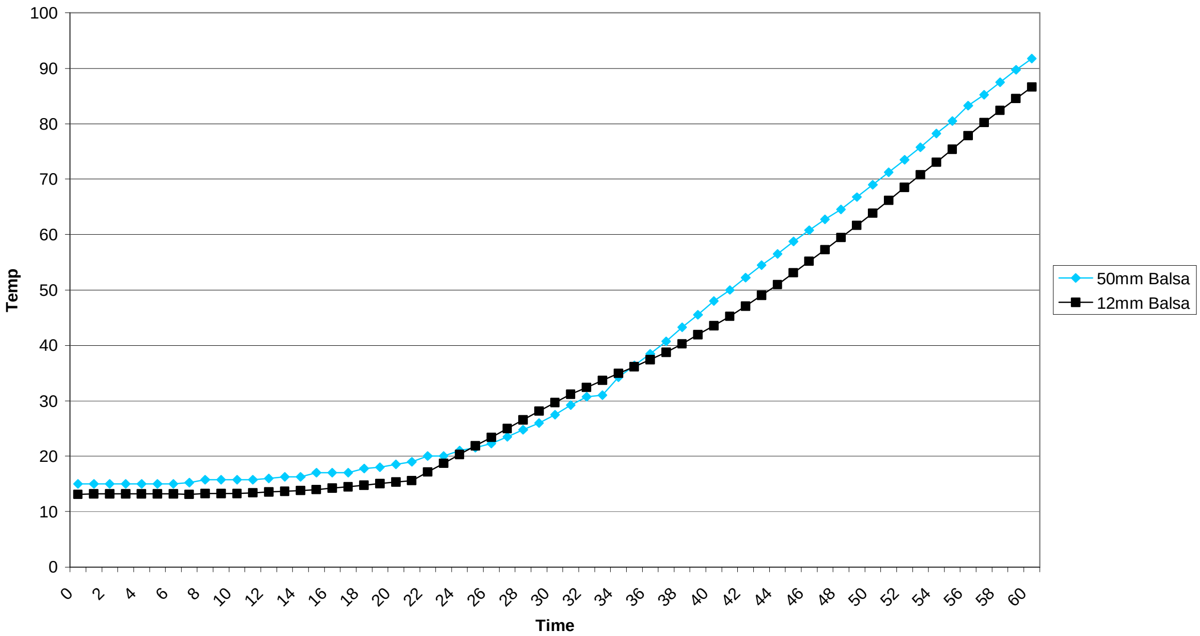
When the thickness of GRP skin in a Balsa cored construction is altered the effect will be the same as that with PVC cored constructions. The exposed face temperature is increased when the skin thickness is reduced.

For testing purposes constructions with thin skins shall be tested as the worst case scenario.

2.3.2 *Effect of Core Thickness of Balsa Cored GRP Construction*

Similarly, the thickness of the core has the same effect on the exposed face temperature. Increasing the thickness of the Balsa core increases the exposed face temperature as can be seen in graph 8;

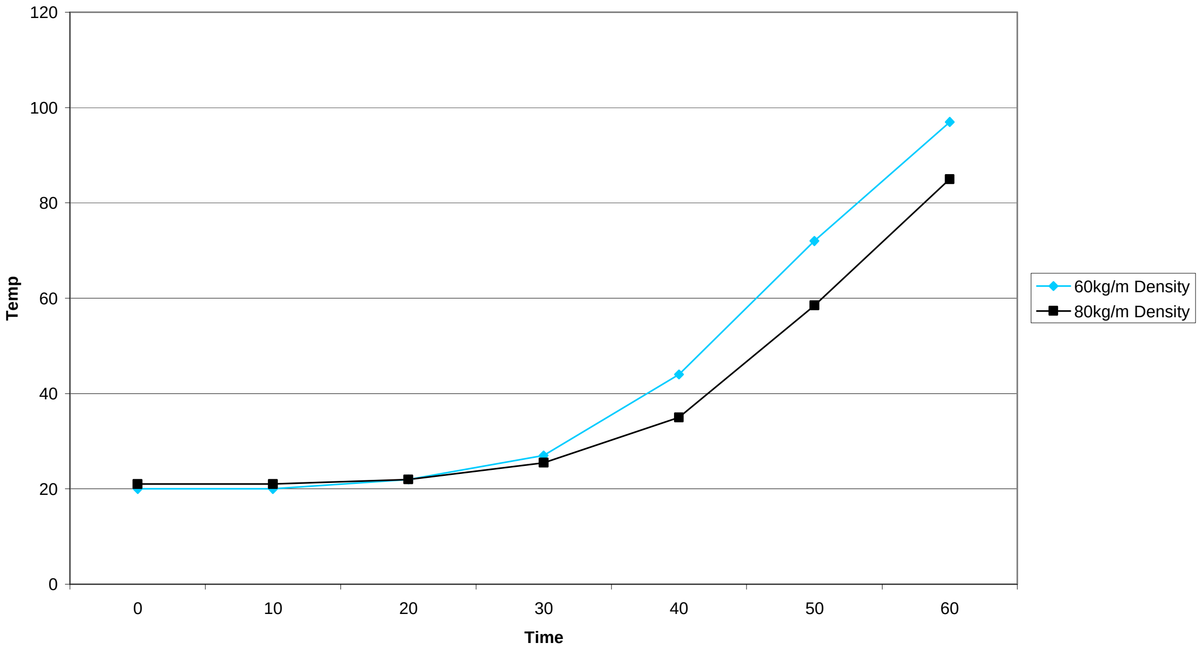
Graph 8 - exposed face temperature with 12mm Balsa and 50mm Balsa



2.4 Effect of Density of Core Materials

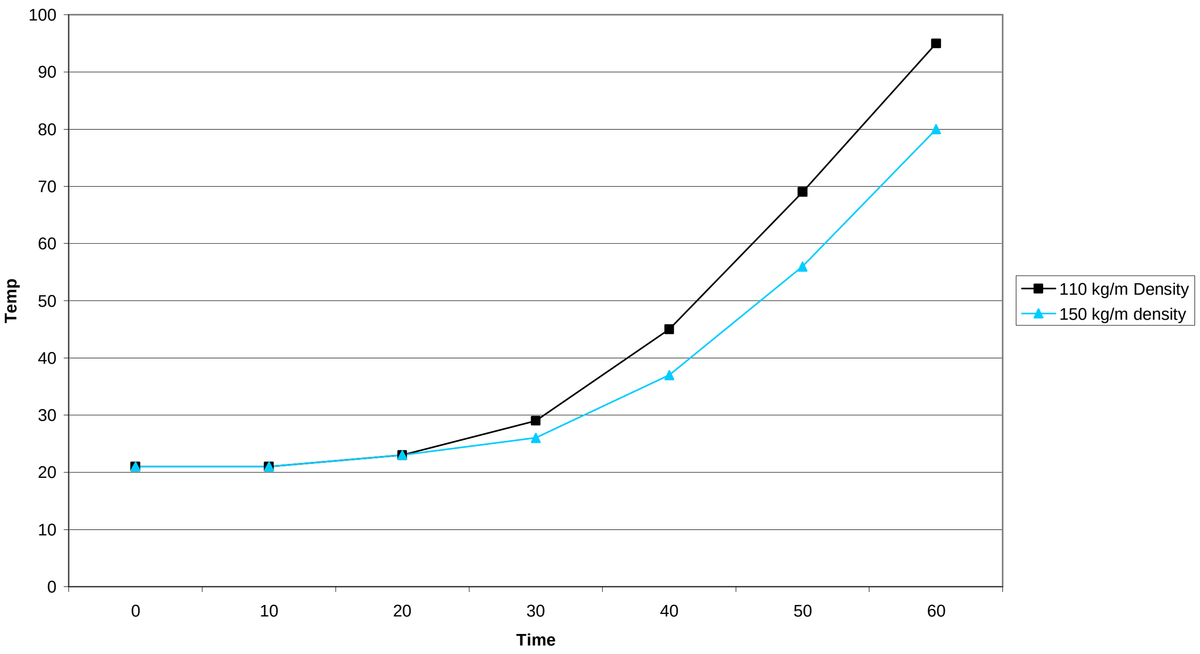
The density of both foam cores (i.e. PVC) and balsa cores is directly related to the heat transmission of the structure. Tests were done to look at the effect of varying the density of panels, see Graphs 9 and 10.

Graph 9 - exposed face temperature with PVC foam core density



As the density of a core increases so does the rate of heat transmission, due in part to the amount of air held within the core material. This means that a structure with a core that is of higher density will transmit heat better and therefore cause the lower exposed face temperature.

Graph 10 - Exposed face temperature with density of Balsa Core

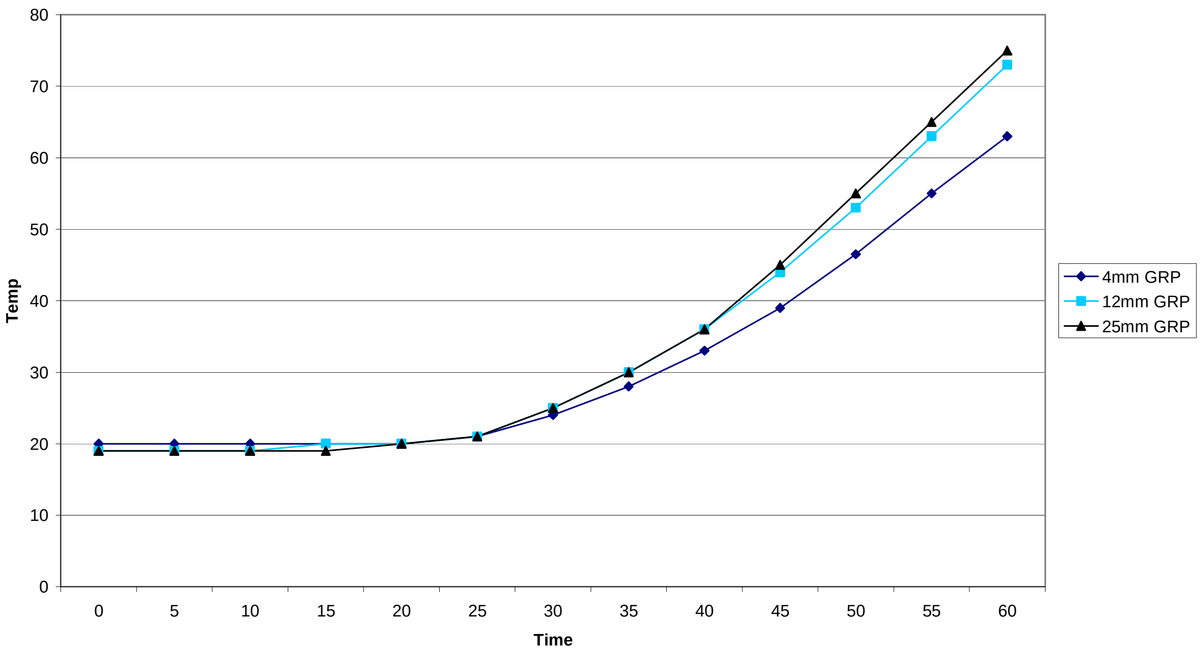


Effectively the lowest density of core results in the worst case scenario.
So an insulation specification tested on a structure using a low density core can be used on a similar structure with a denser core of the same material type.

2.5 Monolithic GRP Constructions

Although it is unlikely that monolithic GRP constructions will need to be considered, tests were done to look into the effect of varying thickness of panels upon the exposed face temperature. We observed that the thicker panels resulted in a higher exposed face temperature (Graph 11).

Graph 11 - exposed face temperature with monolithic GRP Thickness



Thus we can conclude that when testing insulation for use on monolithic GRP constructions, the worst case is the thicker panel.

2.6 Size of test Panels

A number of duplicate tests were performed on small scale (440 x 440mm) size panels, whereas the majority of tests were performed on indicative size tests (1500 x 1500mm) size panels. It was demonstrated that there was insufficient coherence between the two different sizes to allow us acceptance of tests performed on small scale (440 x 440mm) size panels.