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A novel model for interpreting experimental results from sandwich composites exposed to fire conditions

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INTRODUCTION

Composite materials offer a large range of advantages for the marine industry such as light weight, reduction of the maintenance costs and the possibility to create complex shapes. However, in order to have the approval of the authorities for building a SOLAS vessel with composite materials, this alternative design has to show an equivalent level of safety as the prescriptive requirement which is based on the use of metals [1]. Several solutions have been proposed to define new methodologies that demonstrate the required fire safety, these can be distinguished into two main ideologies; A) The tradeoff approach, i.e. staying as close as possible to the prescriptive regulations by making conservative equivalences, often in terms of passive protection, compared to an equivalent prescriptive design [2], and B) The performance based approach that looks into the overall performance in a fire situation. [3].

In case A), the solution requires the experimental testing of different structural components as prescribed by the FTP code [4]...These tests are large scale and consist of exposing the structural element to a predefined temperature curve from one side with the use of a gas fueled oven. Due to the scale and the means required to perform these tests, these result in high operating costs, poor repeatability, unrealistic and/or inappropriate boundary conditions, and poor statistical confidence (Maluk [5]).

The second ideology, B), requires a more fire engineering approach which uses risk analyses along with validated simulation tool which consider the full range of degradation of the materials, including combustion. Furthermore, in order to obtain all required data (thermal and mechanical properties of the composite) for the simulation of different fire scenarios, experiments have to be driven.

The current aim is to present a new system that can answer the main issue of both the aforementioned ideologies. The Heat Transfer Rate Inducing System (H-TRIS) is an experimental rig developed by Maluk et al. [6] that can replicate, at a small scale, the thermal and mechanical stresses required by the FTP code (ISO 834 temperature time curve), and provide thermal and mechanical properties of the studied composite. This can be seen as the link between small scale tests which are used to determine properties of specimen and develop thermal and thermomechanical model as the TGA-DSC [7] [8], cone calorimeter [9], LIFT [10] and Dynamic Mechanical Analysis [11] and the real scale tests as the oven tests within the ISO 834 temperature curve.

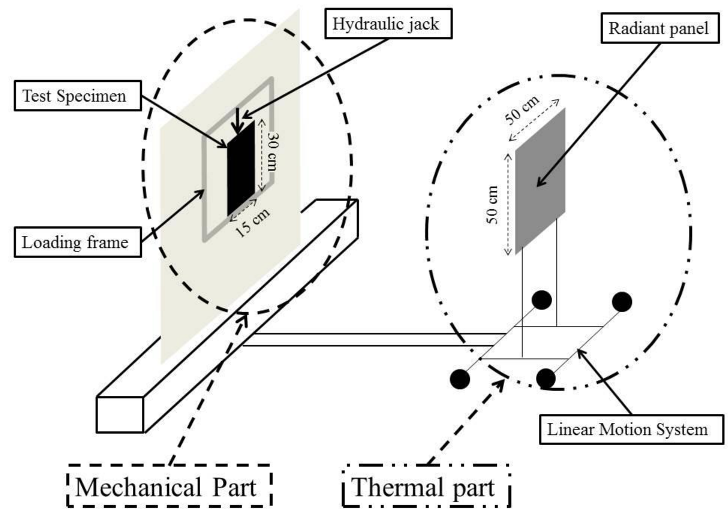

Fig. 1: The two parts of the H-TRIS

An H-TRIS consists of two parts; a radiant panel as thermal source and a mechanical loaded specimen as target, as shown on Fig. 1. Due to the size of the specimen in the current design (area of 30 x 15 cm^2), the square gas-fired radiant panel is only a 50 cm wide but capable of providing a radiant heat flux up to 100 kW/m^2.

The operating cost of the H-TRIS is low because of the small size of the sample, the low consumption of gas, and because it requires only one operator. From the mechanical point of view, as the experiment is at a small scale, the H-TRIS does not require a high performance system. It implies that the mechanical failure mode might be not comparable to the large scale one. But the H-TRIS is a new experimental rig that can be used as a screening experimental rig to test different composite and/or thermal insulation, to obtain experimental data used to simulate or prepare big scale tests, and finally its use requires knowing the thermal properties of the material in order to determine the equivalent radiant heat flux through a thermal model.

THERMAL MODEL

Maluk [5] developed the H-TRIS for studying a composite concrete. Then, to replicate the thermal stress from the ISO 834 temperature time curve, he developed an inverse thermal model based on 1D conduction model, which has the following steps: a) Performing oven test in order to obtain the time function temperature gradient caused due to convection, b) inverse thermal model including the radiant heat flux as boundary condition, c) the final result: the required history of the incident radiant heat flux from the radiant panel.

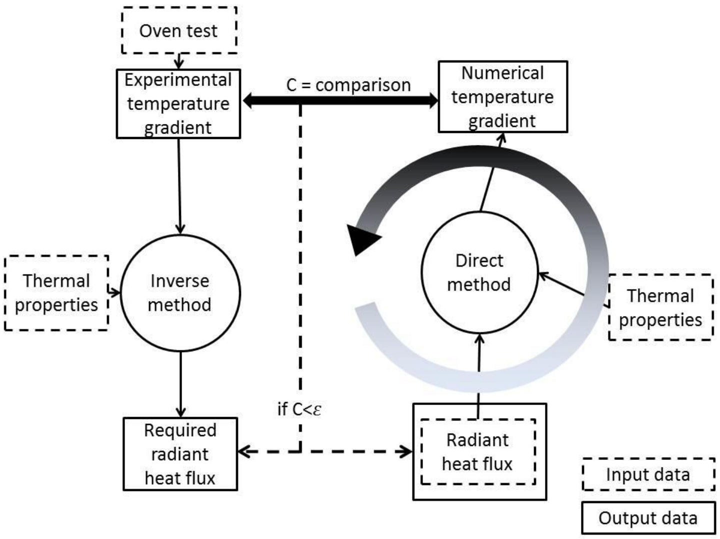

Fig. 2: Schematic of inverse and direct method

In the present study, the inverse method proves to be too complicated to implement, because composites are multi-layered with several compounds and protected by thermal insulation. As a result, too many unknowns arise in the problem, especially related to the contact resistances. The adopted solution is a direct approach based on 1D conduction model with test loops.

The method consists of testing different radiant heat fluxes and comparing the resulting temperature gradient of the material with the one from the oven test. These two models are described in Fig. 2. Whatever the adopted model, one of the key parameters is the thermal properties of the specimen, meaning the conductivity, the density, the heat capacity and the emissivity of the material. Contrary to the case of concrete, thermal properties of composites vary considerably with temperature. Furthermore, apart from the skin properties, the homogeneity of the core material poses significant challenges to the accurate measurement of the thermal properties.. As the model should stay as simple as possible, the real thermal properties are replaced by apparent properties. These properties might be close or not to the real one, but their primary function is to provide realistic results for different radiant heat flux inputs.

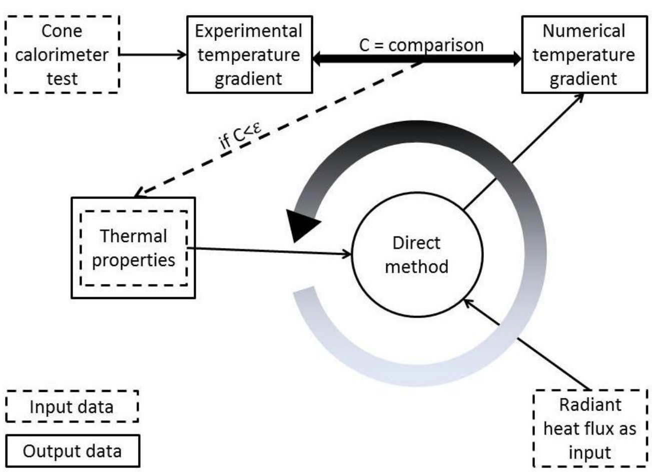

Fig. 3: Schematic method to determine apparent thermal properties of the specimen

To determine these apparent properties, a cone calorimeter is used to inflict a calibrated radiant heat flux to the specimens under study. Subsequently with the use of genetic algorithms and by applying the the direct approach the apparent thermal properties are defined.(see Fig. 3). The scope is that the numerical model is able to simulate the temperature gradient (which is strongly dependent of apparent thermal properties) as measured during the cone calorimeter tests.

A comparison of experimental and numerical temperature gradient leads to the most fitting properties. Fig. 4 shows the comparison of the experimental and numerical temperature for 3 different positions of thermocouples in the depth of a sandwich composite.

The thermal properties of the core of the studied sandwich specimen have been determined from the results presented in Fig. 4. In this approach the global thermal aspect of the sandwich composite is only represented by the core material. The skin is considered as a thermal barrier providing insulation to the core and not contributing to the production of heat. This assumption is not unrealistic given the fact that the skin will be protected by fire insulation, and therefore there will be no ignition of the skin (the skin cannot reach his temperature of ignition, and thermal insulation prevent the presence of a flame).

The next step is to determine the relation between the temperature gradient inside the oven chamber and the equivalent radiant heat flux that needs to be produced by the burner of the H-Tris to reproduce the same thermal gradient at the tested specimens.

CONCLUSION

Through mass loss cone tests and a simple 1D numerical code, the thermal aspect of a sandwich composite has been apprehended. This comprehension of the thermal behavior allows the use of a new experimental rig that can replicate any kind of thermal stress, and can test a large range of mechanical stresses. These tests has a low operating cost compared to real scale test as big oven, due to the small size of specimen and of the rig itself, and is therefore extremely suitable for assessment of composite variations in an early design phase.

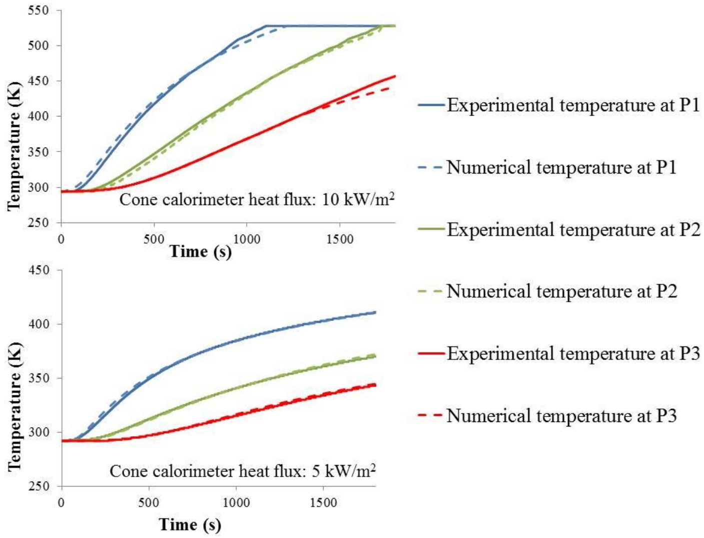

Fig. 4: Comparison of the experimental and numerical temperature of the sandwich core submitted to two radiant heat fluxes

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