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EFFECT OF LOCALIZED FIRE DAMAGE ON FAILURE MODE SHIFTS IN SANDWICH STRUCTURES

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1. INTRODUCTION

Common damage encountered during the service life of the structure spans from a simple tool drop to localized fire damage. Assessing the damage and understanding their effects on structural performance is crucial to design a safe and durable composite structure. Composite sandwich structures with closed-cell foam cores are commonly used in marine and civil engineering structures. When such panels are subjected to localized heat damage due to low-intensity fire or excessive heat, several failure modes could be encountered. Depending on the induced heat flux and damage propagated into the face-sheet or core, the sandwich compression strut could potentially fail by face sheet instability at the location of the damage, or by core shear instability (shear crimping). This shift in failure modes of sandwich structures is directly related to the amount heat transferred into the core, and consequently, decomposing and charring the sandwich structure. This experimental work presents the post-fire failure mechanisms and residual properties of sandwich structures when subjected to axial loads. Using the cone calorimeter test apparatus, coupled with thermocouples on both sides (top and bottom) of the samples , measured temperature profiles are presented for the PVC foam cores (H80 and H200) and sandwich structures for the induced 10 and 30 kW/m^2 heat fluxes.

2. BACKGROUND AND EXPERIMENTAL TESTING

For an undamaged sample, the axial load resisted by the structure results in equal axial deformations of the facings and core, thus facesheet fracture and even global or local instability occur under “controlled axial displacements”. Several researchers already investigated these failure modes. However, in a post-fire scenario, the axial load will be redistributed to the stiffer part of the structure (undamaged facing/core), leading to local 3D-dimensional effects near the heat-damaged zone. This “controlled force loading” phenomenon leads to loss of strength prior to elastic stability failure. Several researchers investigated the post-fire mechanical properties of sandwich structures [1] and wrinkling at high temperature [2]. Specifically, Birman et al. [2] developed a theory where a desirable variation of the stiffness can be achieved by varying the mass density through the thickness of the core. Their specific application targeted wrinkling in a functionally graded core. This work investigates the failure modes related to low-to-medium localized fire exposure, and use the Digital Image Correlation (DIC) technique to measure the strain field and displacement prior to failure. The materials selected to manufacture the composite panels are shown in Table 1. The water jet technique was used to cut the panels into the desired dimensions (Fig. 1). For the tensile test samples, the two end sections were tabbed with G10 Epoxy on each side of the specimens using urethane adhesive (Lord adhesive 7150A/B H, LORD corporation) and then prepared according to testing protocol proposed by Toubia et al.[3]. Fig. 1 shows the dimensions and geometry of the test samples.

Table 1: Materials selection and sandwich construction.

Facesheet Construction/Areal Weight	Core	Resin	Catalyst	Fabric Architecture	Molding Process
4 Plies E-BXM-1708 E-Glass, 883 gr/m^2 total. [+45°(304 gr/m^2), -45°(304 gr/m^2), Chopped Mat (275 gr/m^2)] (Vectorply Corporation®)	H80 and H200 PVC foam (Divinycell® Inc.)	DERAKANE 610 C-200 Epoxy Vinyl Ester Resin (Ashland Inc.)	1.25% Organic Peroxide, Cadox®	Double bias, ±45° [+45/-45/Mat]	VARTM Infusion with 28 Hg Vacuum Pressure

To control the region of thermal decomposition at the center of the samples, the specified specimens for tensile and edgewise compression tests were wrapped in Aluminum foil on all sides except for the top middle section (Fig. 1) facing the heater. The ignition spark was exactly centered over the unwrapped area and the shutters were left open until either the sample ignited or maximum time of 7 minutes if the sample did not ignite. Following exposure, the samples were cooled to room temperature under an exhaust hood and were covered with a stainless steel snuffer. Char thickness through the samples was then measured before performing post-fire mechanical testing. Fig. 1 below shows couple of representative samples using thermocouples to measure through-the-thickness temperature. Localized damaged was induced using the cone calorimeter heater. It is worth mentioning that at 10 kW/m^2 flux, a discoloration of the facesheet followed by facesheet-core interface debond occurred, while at a flux of 30 kW/m^2, partial damage/char of the core was noticeable.

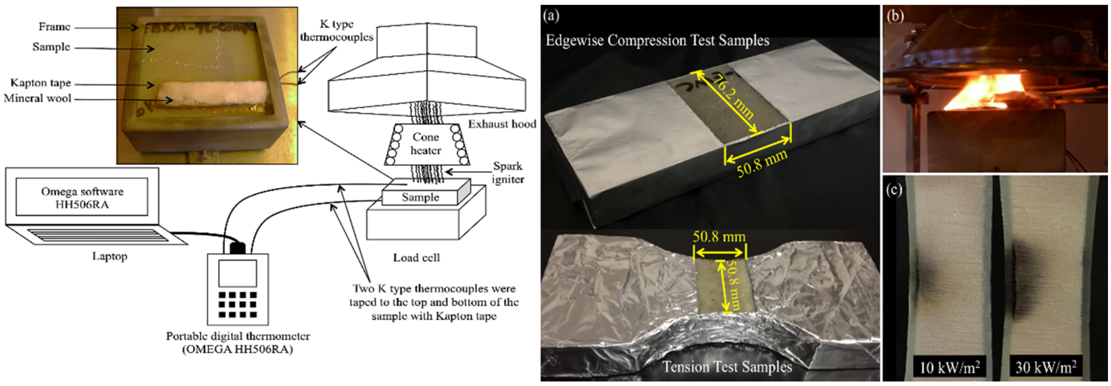

Fig.1: Left: Cone Calorimeter experimental procedure, Right: (a) Samples partially covered with aluminum foil except for a 25 cm^2 on top exposed area, (b) tested sample was placed 25 mm under the cone heater on an Aluminum foil wrapped ceramic brick, (c) samples clearly ignited and burned through-the-thickness.

Fig.below shows some representative experimental data on the compression behavior of several heat treated samples. The baseline sample experienced global buckling, whereas samples exposed to one sided heat exposure exhibited skin wrinkling and core shear instability (10 kW/m^2 and 30 kW/m^2, respectively). This shift in failure modes in the presence of damage must be taken into account to assess the service life of the structure, or even if a repair or replacement is attempted.

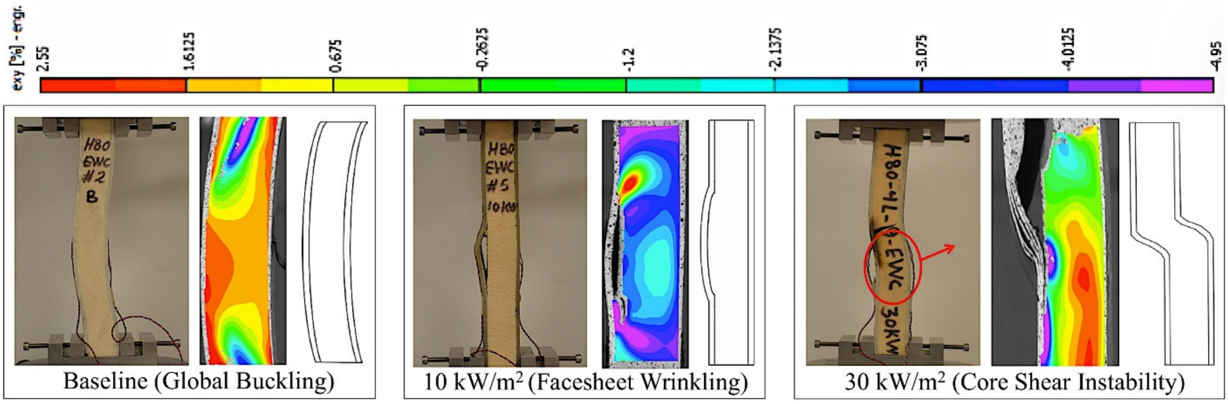

Fig.2: Edgewise compression and DIC images showing side view and shear strain distributions at incipient compression failure.

3. RESULTS AND CONCLUSIONS

The performed experimental tests demonstrated that the post-fire behavior of sandwich construction is governed by dependent sets and variables: the density of foam, the thermal conductivity and diffusivity of the foam core, and the amount of damage penetrating the core (char depth). The presented results revealed that depending on the heat damage propagating into the sandwich panel, a switch in failure modes will occur from global to local buckling modes. The foams significantly affected the measured temperatures, as well as the char depths. The H200 foam is a denser foam and therefore conducts heat better than the H80 foam (which is a better insulator), and this explains the results presented in Fig. 3. In addition, the sandwich panels with H200 foam core experienced less reduction in axial tensile modulus and strength than the sandwich samples with H80 foam core (Fig. 4).

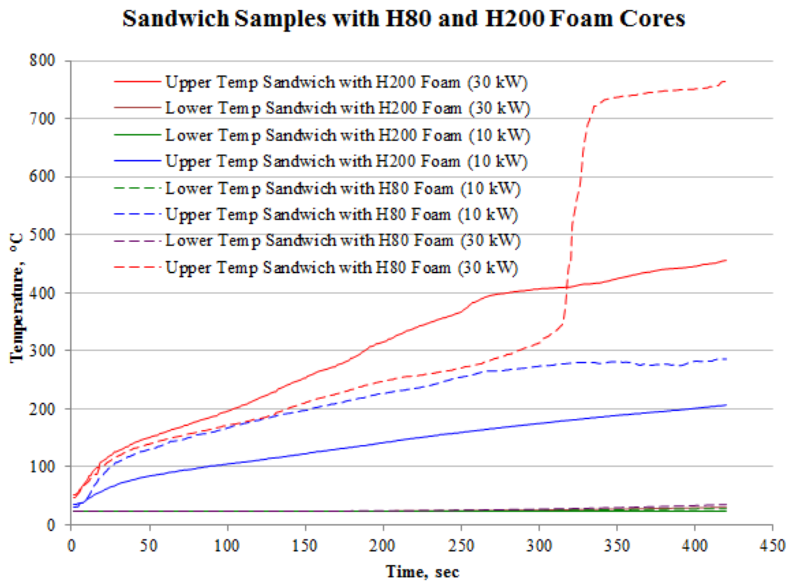

Fig.3: Upper (top facesheet) and lower (bottom facesheet) temperature profiles for sandwich samples with H80 and H200 foam cores.

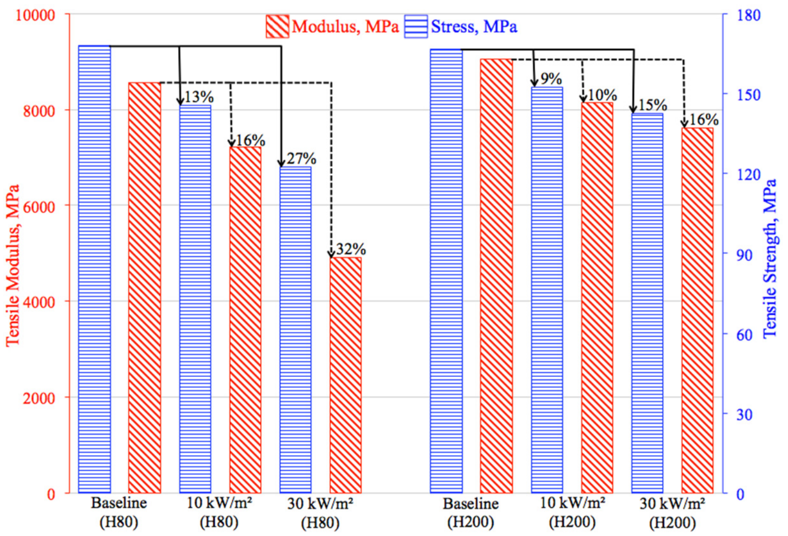

Fig.4: Tensile strength and modulus for sandwich samples with H80 and H200 foam cores (percentage reduction shown with respect to the undamaged baseline samples)

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