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Investigation of Composite Façade Mullions

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CERTIFICATE OF AUTHORSHIP/ORGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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List of Notations

A_c	Total areas of polyamide inserts
A_t and A_b	Area of top and bottom skins, respectively
b	The width of beam
c	Elasticity constant (N/mm^2) – Chapter 3
c	Height of core – Chapter 7
c_0	Elasticity constant under quasi-static loading
c_t and c_b	Distance from neutral axis to the centroidal axis of top and
d_t and d_b	Height of top and bottom skin
D_1 to D_4	Integration constants which will be determined by
E	Young's modulus of the material
E_c	Young's modulus of core material
EI	Flexural stiffness of the beam
f_e	Conventional elastic limit
F_k	Force needed to maintain relative motion between two bodies
F_{max}	Maximum shear/tensile load (N)
F_s	Force just sufficient to prevent the relative motion
G_c	Shear modulus of the core.
I_t and I_b	Second moment of inertia of top and bottom skin
l	Length of the test specimen (mm)
M	Applied bending moment
M_T^I	Total bending moment existing at the section
M_{xx}^i	Bending moments at top and bottom skins ($i = t, b$)
$N.A$	Neutral axis of the section
N_T^I	Axial force existing at the section
N_{xx}^i	Axial forces at top and bottom skins ($i = t, b$)

n	Exponent characterizing the degree of hardening of the curve
P	Force normal to the interface between the two sliding bodies
P^{II}	Concentrated load P applied on sub-structure II
P_t^I and P_b^I	Concentrated load P applied on sub-structure I at top and bottom skin
P_t^T and P_b^T	Concentrated load P applied on the whole structure at top and bottom skin
p^{II}	Vertical peeling stress at the interface between core and skins
p_t^I and p_b^I	Vertical normal stress at top and bottom contact layers, respectively.
Q	Tensile strength (N/mm)
Q_T^I	Total shear force existing at the section
Q_{mean}	Mean value of the measured values of transverse tensile strength at the test temperature
Q_{xx}^i	Shear forces at top and bottom skins ($i = t, b$)
q^{II}	UDL applied on sub-structure II
q_t^I and q_b^I	UDL applied on sub-structure I at top and bottom skin
q_t^T and q_b^T	UDL applied on the whole structure at top and bottom skin
T	Shear strength (N/mm)
T_{mean}	Mean value of the measured values of shear strength at the test temperature
u_t^0 and u_b^0	Horizontal displacement at the neutral axis of top and bottom skin,
w^I	Vertical displacement of the skins and core for sub- structure I.
w_c^{II}	Displacement of core of sub-structure II
x_1 and x_2	Distance equal to one-third of span length and
$\varepsilon_{0,e}$	Residual strain corresponding to the stress f_e
ε^{pl}	True plastic strain
ε^t	True total strain
σ_v^c	Normal compressive stress in vertical direction in the core

ΔF	Increase of the shear load (N)
$\Delta\delta$	represents the corresponding displacement of ΔF (mm)
$\dot{C}$	Elasticity constant under a specific strain rate loading
γ	Coefficient relating to the type of profile
ρ	Radius of curvature
σ	True stress
s	Estimated standard deviation
γ	Shear strain of the core.

Abstract

Modern curtain wall systems are typically designed with extruded aluminium members. As a load bearing vertical element of the curtain wall system, mullions are also made of aluminium extrusions with glass fibre reinforced polyamide acting as a thermal break joining the external and internal extrusions together. This research is focused on the behaviour of this type of thermal break composite façade mullions under quasi-static loadings.

Literature survey was carried out. Past research works on of the thermal break façade mullions was studied, as well as the current European standard specifying the performance requirement, proof and test for the thermal break profiles. Sandwich theory was studied and laid as a foundation of this research. Literature regarding material properties of aluminium and polyamide; interfacial action between aluminium and polyamide and composite beam bending were investigated and appropriate methodologies were adopted.

To investigate the behaviour of the thermal break façade mullions, a typical mullion section was studied. This is a symmetrical composite section made of external and internal aluminium extrusions and joined by a glass fibre reinforced polyamide core. Experimental investigations were carried out to find the section shear and tensile capacity as well as the connectivity constant. The section capacity tests were performed at various temperatures under quasi-static loadings to investigate the temperature effect. Experiments under high strain rate loading have been performed at room temperature to find the relationship between section shear and tensile capacity and loading rates. As the mullions usually work as a simply supported beam under wind, temperature and earthquake loads, bending behaviour is necessary to be investigated. Experiments of four-point bending were performed on this façade section. Specimens of three for four sets of span length each were tested at room temperature under quasi-static loadings.

Numerical simulations for the section shear and tensile tests, as well as four-point bending tests were carried out. Interfacial actions between aluminium and polyamide were modelled based on Coulomb's friction theory. Two new failure models – "Proposed progressive failure model" and "Proposed partitioned multi-phase beam failure model" were developed and applied to section shear capacity model and beam bending models to simulate the interface failure. ABAQUS software was chosen to

perform the simulations. The FE modelling results were compared with the experimental results in detail.

The results of experimental investigations on section capacities at various temperatures concluded that the section shear and tensile capacity as well as connectivity constant increased with decreased temperature. Experiments under high strain rate loads showed the section shear and tensile capacity was not sensitive to strain rate. However, the connectivity constant showed a clear trend of strain rate sensitivity.

Comparisons between experimental results and the numerical results were made. Failure modes observed from the shear and tensile experiments were repeated by the FE shear and tensile models. Load vs slippage graph obtained from shear model matched the experimental one very well. The load-displacement graph generated by the FE tensile model with equivalent material properties agreed well with the experimental one.

Results obtained from the FE beam models correlated to the experimental results very well. Load vs mid-span displacement graphs produced from both experiments and the FE models showed consistent peak loading capacity. The three-stage progressive failure mode observed from the experiments was reproduced by the FE models. Mid-span strain distribution diagrams at elastic range, generated by the FE models, were compared with the experimental ones as well. It was found that the FE model results were relatively consistent with the experimental ones. However, further improvements can be made in future studies. The relationship between moment and curvature at mid-span bottom extreme fibre obtained from the FE models confirmed consistency with experimental results.

A proposed frame work for an analytical solution of four-point bending of this type of composite thermal break façade profile in the elastic range was presented in this thesis. Based on the sandwich theory and superposition approach, formulations were derived to work out deflection and stresses, including peeling stresses between aluminium skins and polyamide core. Due to limited time and scope, the analytical solution has not been verified by experimental and numerical works in this research. It is recommended that experimental and numerical investigations be carried out to verify the analytical solutions and apply them to the industry applications in future studies.

Another asymmetrical thermal break profile was also investigated numerically. Finite element models of the section shear and tensile capacity were established by ABAQUS software. The proposed progressive failure model was successfully applied to simulate the failure mechanism in the shear model. A four-point bending beam model was built in ABAQUS software with the proposed partitioned multi-phase beam failure model, effectively simulating the interface failure mechanism. The FE models generated similar trends as the typical section models, especially shear and tensile capacity models. However, variations in the beam model were observed. Further experimental investigations are required to confirm the phenomenon revealed by the numerical investigation in future studies.

Further research on the thermal break façade mullions can be extended to further investigation of strain rate sensitivity of section shear and tensile strength by performing large quantities of experiments and numerical simulations under high strain rate loadings. Future studies to carry out experimental and numerical investigations to verify the analytical solution and extended into industrial applications are highly recommended as well. Future studies involving experimental investigation of the asymmetrical thermal break sections to confirm the behaviour shown by the FE modelling is also valuable to provide further insight.

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