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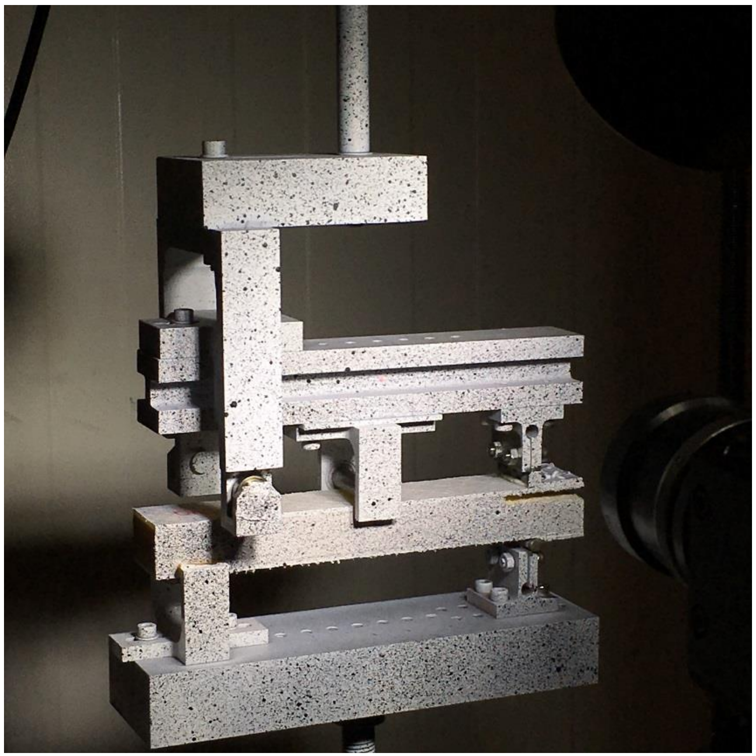
Low temperature testing of debonded PVC foam cored sandwich composites for naval vessels



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DTU Mechanical Engineering
Department of Mechanical Engineering

Outline

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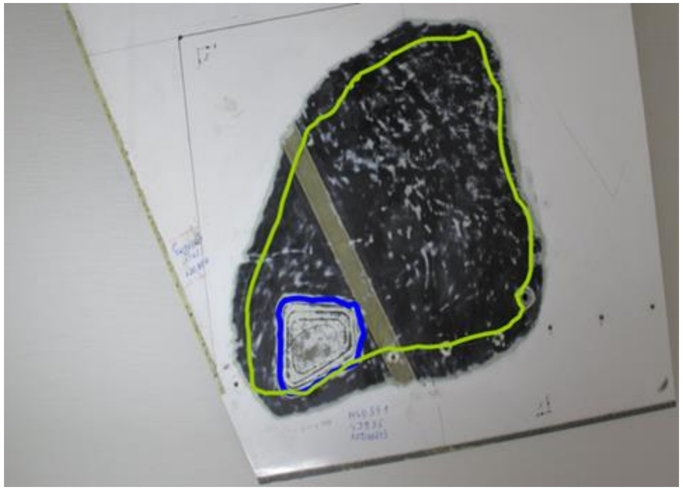
- ❑ MMB specimen
- ❑ MMB Formulation
- ❑ Implementation of tests
- ❑ G-control test methodology
- ❑ Experimental Results

Background and motivation



+ superior stiffness/weight ratio
+ Prolonged fatigue life
+ Minimization of maintenance
+ Lack of corrosion

- Experience has shown that a common problem is the existence of debond at the face/core interface of the sandwich
- Debonds can be introduced during the manufacturing processes as a result of poor resin flow or during service due to accidental overloads

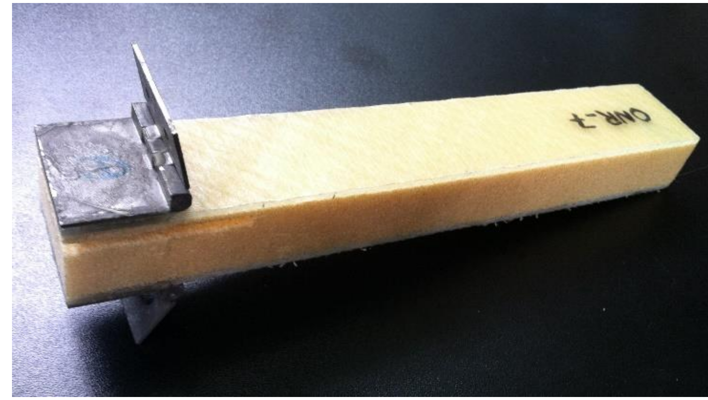
Sandwich composites in naval ships

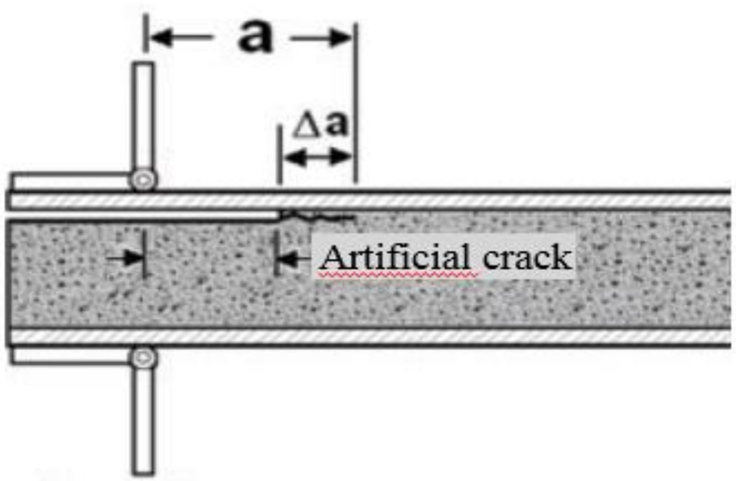
- Naval vessels are expected to operate in a variety of climatic conditions
- Arctic operations are becoming increasingly important for the Navy due to global warming
- It is important to characterize the low temperature fracture of sandwich composites

Danish naval vessel in ice filled waters

MMB Specimen

- Divinycell H100 cross-linked PVC foam
- E-glass/epoxy non-crimp multi-axial (0/45/90/-45) Devold AMT DBLT-850-E10





Mechanical properties of H100 PVC foam core and E-glass sheets.

Properties	value
Foam core: H100 PVC	
Cell size [mm]	0.45
Density [kg/m^3]	100
Compressive modulus [MPa]	135
Shear modulus [MPa]	35
Face sheet: DBLT-850 (0/45/90/-45)	
Young's modulus (E_x) [GPa]	18.6
Poisson's ratio (ν_{xy})	0.4
Shear modulus (G_{xy}) [GPa]	6.1

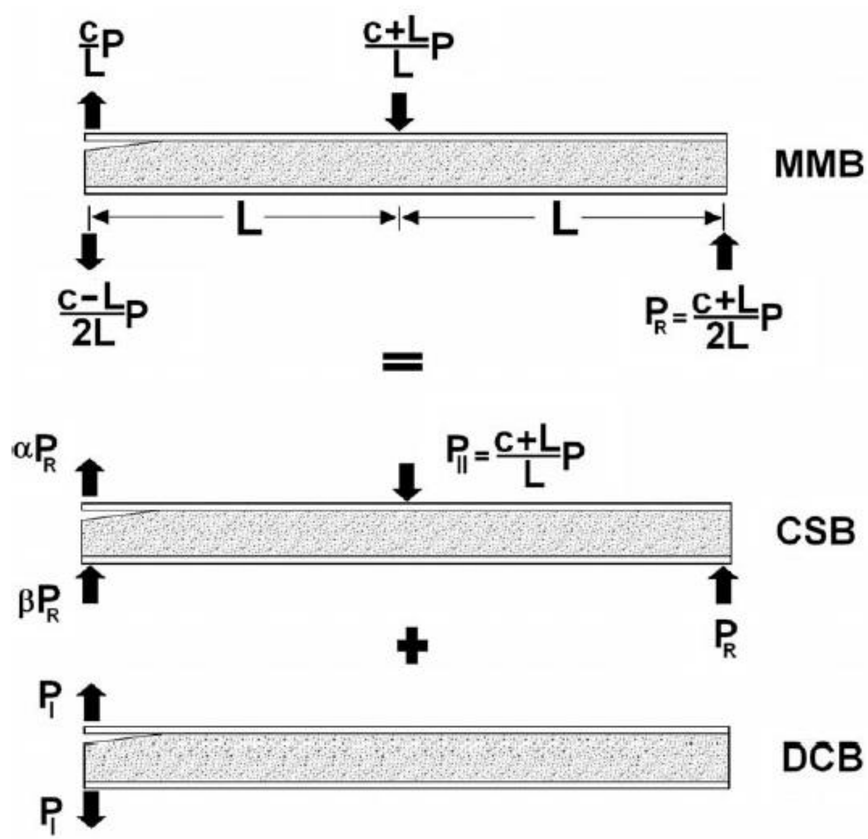
MMB formulation

$$\alpha = \left[\frac{\frac{a^3}{3}\frac{1}{D-\frac{B^2}{A}} + \frac{a}{k}\frac{1}{G_f h_f + G_{xz} h_c}}{\frac{a^3}{3}\frac{1}{D-\frac{B^2}{A}} + \frac{a}{k}\frac{1}{G_f h_f + G_{xz} h_c} + \frac{a^3}{3}\frac{1}{\frac{E_f h_f^3}{12}} + \frac{a}{k}\frac{1}{G_f h_f}} \right]$$

$$C_{DCB\_lower} = \frac{a}{b}\left[\frac{1}{h_c G_{xz}} + \frac{a^2}{3(D-\frac{B^2}{A})}\right]$$

$$C_{DCB\_upper} = \frac{4}{E_f h_f^3 b}\left[a^3 + 3a^2\eta^{1/4} + 3a\eta^{1/2} + \frac{3}{2}\eta^{3/4}\right]$$

$$C_{CSB} = \frac{L^3}{6bD_{intact}} + \frac{L}{2h_c b G_{xz}} + \frac{a^3}{12b}\left[\frac{1}{D_{debonded}} - \frac{1}{D_{intact}}\right]$$



MMB formulation

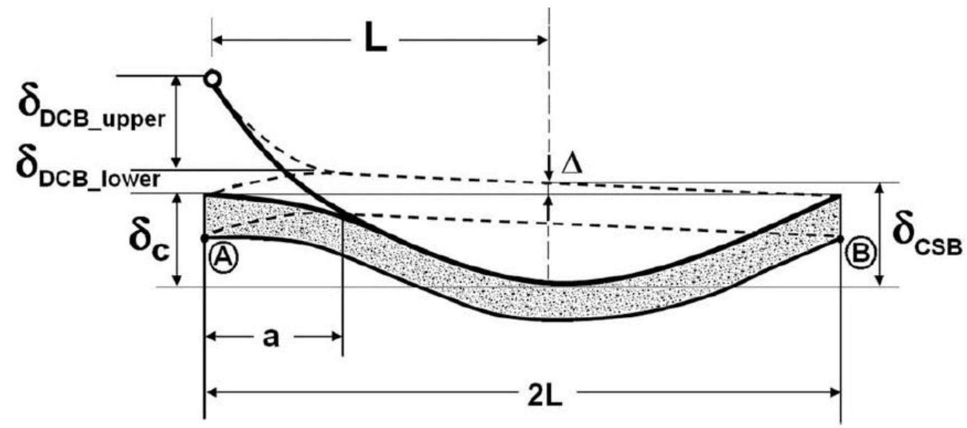
- The mode-mixity phase angle has been determined using FEA and the CSDE method [C. Berggreen el al. 2007]

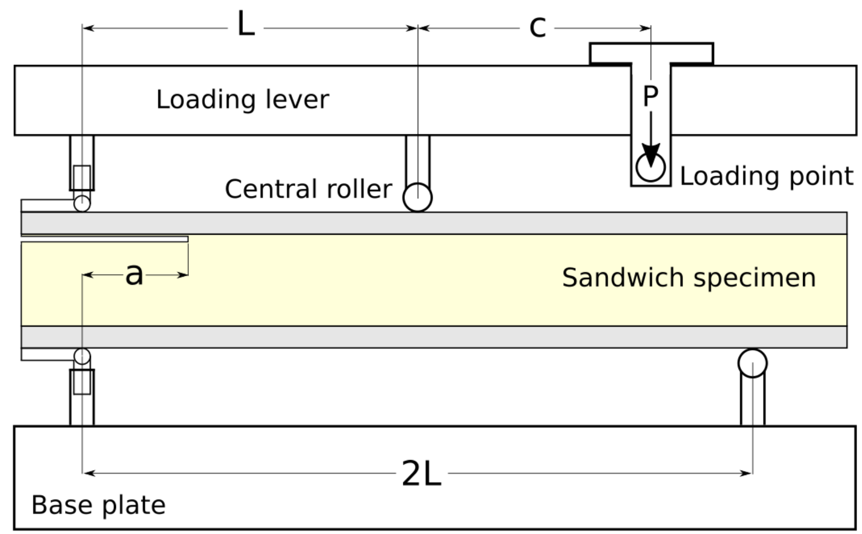
- The reduced mode-mixity formulation has been applied

- The mode-mixity at the crack tip is controled by the lever arm distance, c.

$$C = [\frac{c}{L} C_{DCB\_upper} + \frac{c-L}{2L} C_{DCB\_lower}](\frac{c}{L} - \alpha \frac{c+L}{2L}) + (\frac{c+L}{L})^2 C_{CSB}$$

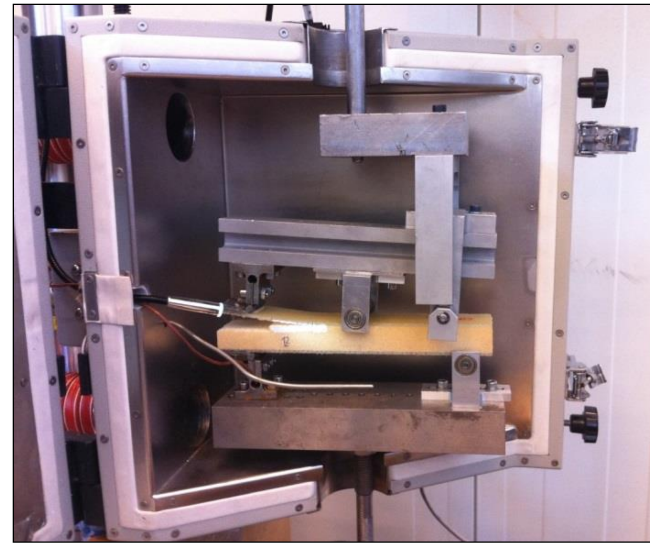
$$G = \frac{P^2}{2b^2} \left(\begin{array}{l} \frac{c}{L}(\frac{c}{L} - \alpha \frac{c+L}{2L}) \frac{12}{E_f h_f^3} [a^2 + 2a\eta^{1/4} + \eta^{1/2}] + \\ \frac{c-L}{2L}(\frac{c}{L} - \alpha \frac{c+L}{2L})[\frac{1}{h_c G_{xz}} + \frac{a^2}{(D - \frac{B^2}{A})}] + (\frac{c+L}{L})^2 (\frac{a^2}{8}[\frac{1}{D_{debonded}} - \frac{1}{D_{intact}}]) \end{array} \right)$$





Implementing MMB test inside a climatic chamber

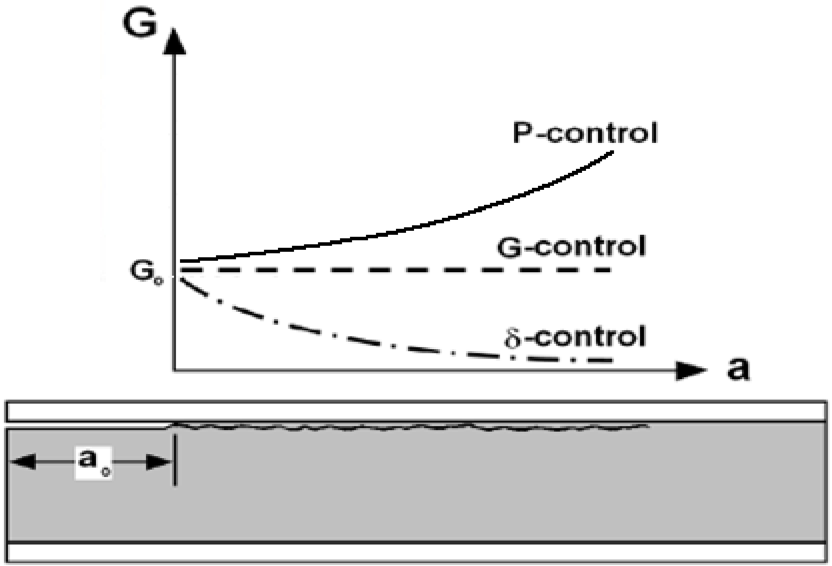
- Quasi-static and fatigue tests were carried out at mode I and mode II dominant at -20° C as well as room temperature, 23° C.

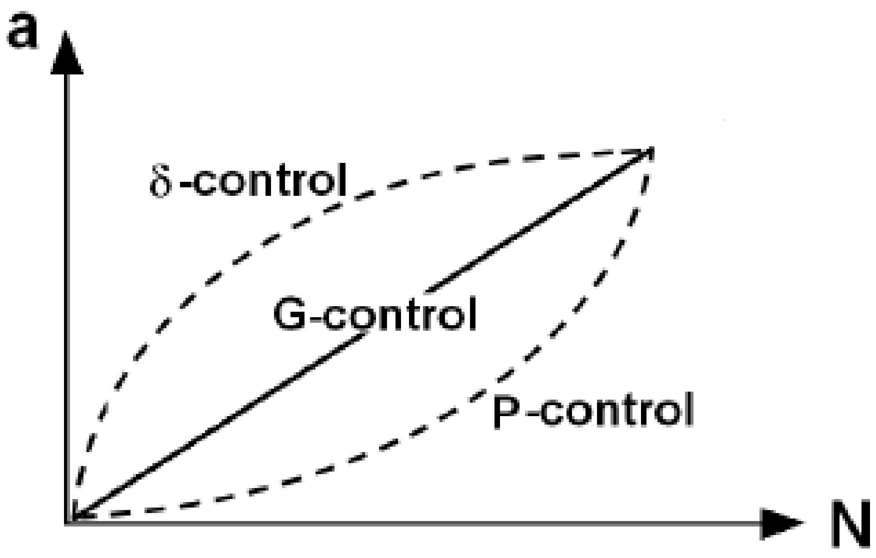


Core density	Face sheet material	Specimen length [mm]	Specimen width [mm]	Face thickness [mm]	Core thickness [mm]	Mode I (Ψ_R=4.4°)	Mode II (Ψ_R=-23.9°)	Low temp.	Room temp.	Fatigue	Static	No. of specimens
H100	E-glass/epoxy	220±1	35±0.5	2	20	Yes	No	Yes	Yes	Yes	Yes	8
H100	E-glass/epoxy	220±1	35±0.5	2	10	No	Yes	Yes	Yes	Yes	Yes	8

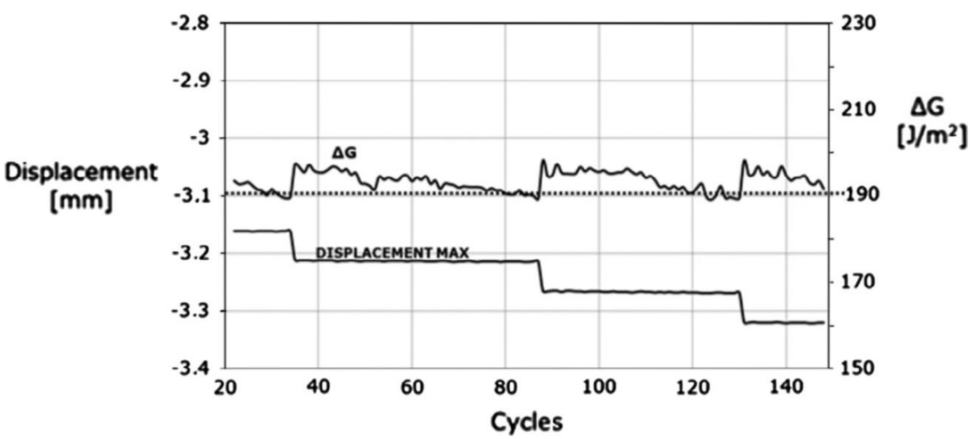
G-control test methodology

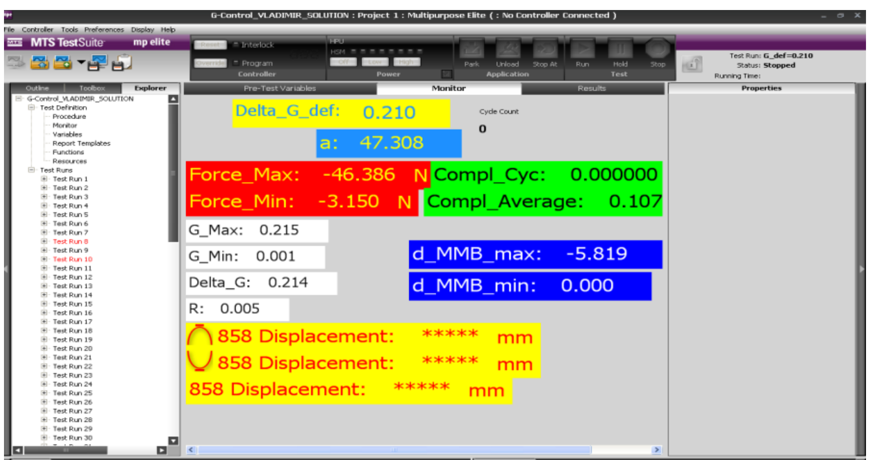
- The G-control test methodology allows highly controlled cyclic crack growth testing using real-time control of the cyclic energy release rate (*ΔG*).

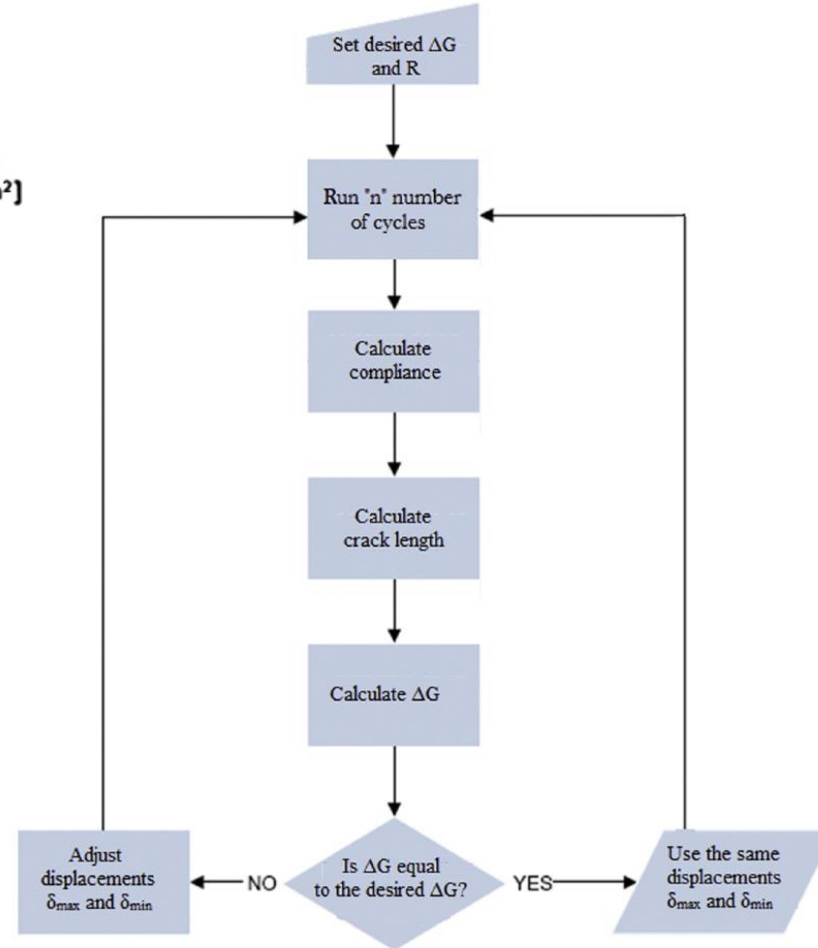




G-control test methodology







Conclusion

The preliminary work has shown:

- It seems that the fracture toughness of a typical naval type foam core sandwich composite decreases at low temperatures.
- It seems that the intensity of the degradation depends on the mode-mixity as well.
- It seems that the stiffness properties of the foam core sandwich composite remains same at low temperatures.
- It seems that the crack growth speed increases at low temperatures.
- It seems that the increment of crack growth speed depends on the mode-mixity as well.

ACKNOWLEDGEMENT

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Thank you for your attention!

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[2] M. Manca, C. Beggreen, L. A. Carlsson and P. Bortolotti, "Fatigue characterization of a face/core interface crack in PVC foam core sandwich composite beams using the G-control method," Sandwich Structure and Materials, DOI: 10.1177/1099636215603049, 2015

[3] M. Manca, C. Berggreen and L. A. Carlsson, "G-control fatigue testing for cyclic crack propagation in composite structures," Engineering Fracture Mechanics, vol. 149, pp. 375-386, 2015