DYNAMICAL MECHANICAL ANALYSIS AND FRACTURE TOUGHNESS OF CARBON REINFORCED EPOXY COMPOSITES

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ABSTRACT

The objective of this research is to evaluate the mechanical properties of a cross-ply and quasi-isotropic symmetrical plain weave carbon-epoxy laminate produced with a vacuum bagging method and a autoclave processing method for a given set of epoxy/carbon fabrics types. Autoclave processed laminates exhibit higher static strengths, higher moduli in tension, compression and bending, but lower Charpy impact toughness. New findings about materials properties were deducted from dynamic multi-frequency tests between 1 to 50 Hz where it was found that the activation energy is 1.8 times higher in autoclave processed specimens. Moreover, autoclave laminates have, on an average 1.7-times lower damping ratio in the glassy plateau region and a 3-times lower peak damping ratio in the glass transition region than wet-layup specimens.

SAMPLE PREPARATION

The subject of the study were **eight-ply $[0]_8$** laminate composite and an **eight-ply laminate composite** with the stacking sequence (45/0/45/0/0/45/0/45) or **$[(45/0)_2]_s$** produced from orthotropic (cross-ply, or 0/90) woven -> **Fig. 1.**

Wet-layup method with vacuum bagging

- **8 plies** of dry plain weave **carbon fabrics Sigratex® CW200-PL1/1** (7 μm fibers (200 tex) of **500 × 500 mm²** impregnated with epoxy-resin **MGS® 285** (Rm=70-80 MPa, E=3–3.3 GPa, A= 5–6%, ρ=1.19 g/cm³)
- **Peel ply** on the top of the impregnated fabrics + polyester-based 2.5 mm thick non-woven absorber for removing the excess resin after the vacuum
- **The total production time was 50 min**, followed by **24 hours of initial curing** at room temperature. Then, the plate was subjected to **post-curing at 80 °C for 8 hours**.

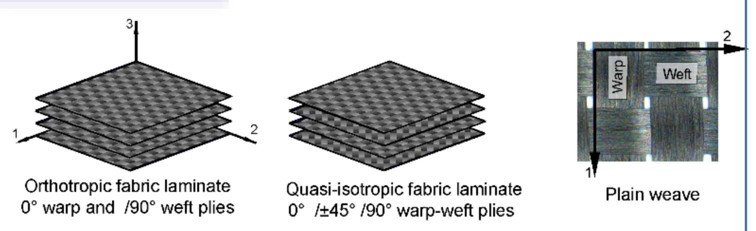

Fig. 1. Biaxial woven laminates

Autoclave prepreg processing

- **8 plies** of plain weave **prepreg** material **CC202 ET 445** (7 μm fibers (200 tex)
- **Peel ply** on the top of the laminate + 3 mm thick non-woven absorber for even distribution of vacuum pressure over the plate and inserted into the autoclave.
- **A vacuum level of 30 kPa** was established and the **pressure of 400 kPa.**
- The heating rate of **3°C/min** and the holding time of **100 minutes at 130°C** was used (Fig. 2).

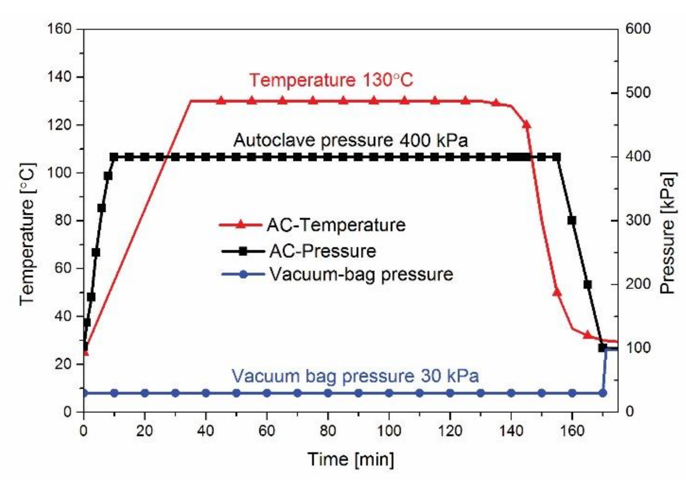

Fig. 2. The autoclave manufacturing cycle

MACROSTRUCTURE AND FIBRE VOLUME FRACTION (*according to ASTM D2584*)

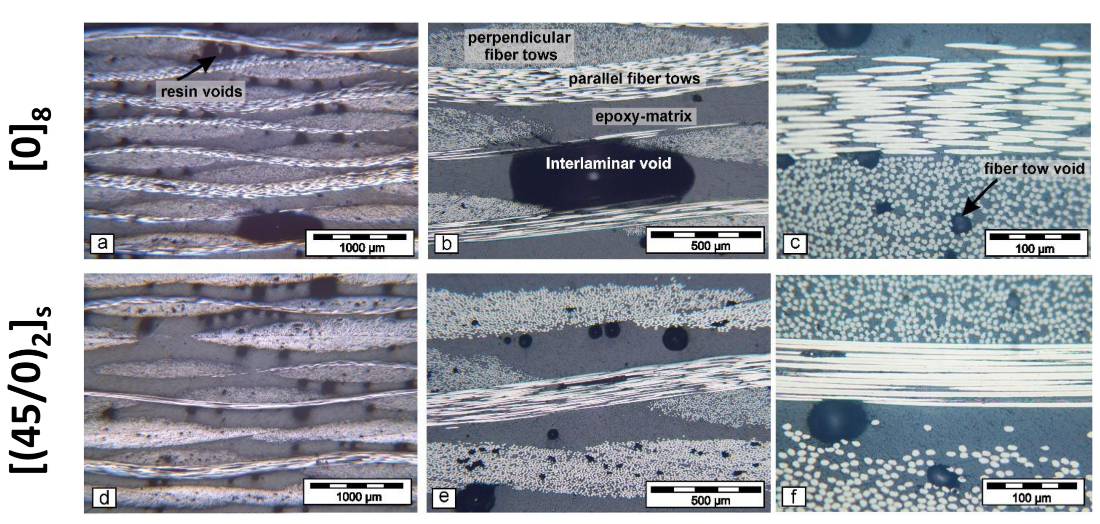

Fig. 3. Microstructures of wet lay-up and vacuum-bagged specimens.

Wet-layup & vacuum-bagged :

- **Highly porous** laminates
- Overall **thickness of 2.8 mm**
- **32% fibre volume content**
- **Void content**: **4.8–6.8 %**
- 3 void groups:
  - **Interlaminar** voids (>500 um)
  - **Resin** voids (10–100 μm)
  - **Fibre-tow** voids (30–50 μm)

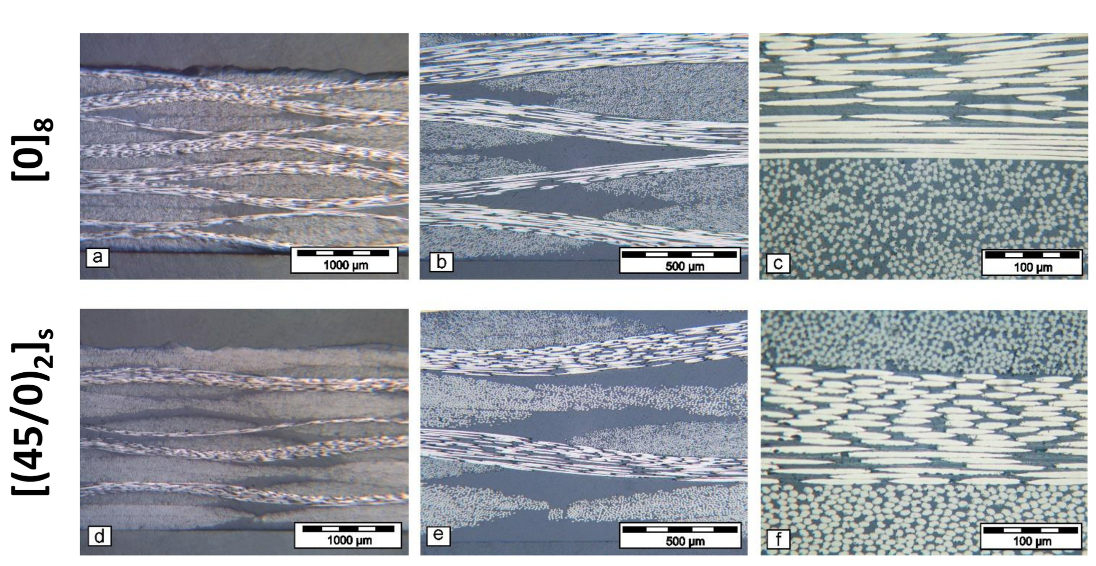

Fig. 4. Microstructures of autoclave processed composites

Autoclave-prepreg:

- **NON-porous, Void FREE microstructure**
- Overall **thickness of 2.05 mm**
- **44% fibre volume content**
- **Higher fiber density & smaller resin-rich areas**

TENSILE, COMPRESSIVE & FLEXURAL TESTING

- **Smaller E** and **strengths** with the **wet-layup laminates.**
- The **wet-laminated $[0]_8$** laminate **reached only 76%** of the **tensile**, **58%** of **compressive** and **68%** of **flexural strength** of **$[0]_8$ autoclave prepreg laminate** ***(Fig. 5****(a-c-e)*).
- **The elastic moduli, strengths and ultimate strains decrease in quasi-isotropic $[(45/0)_2]_s$ stacking sequence in comparison with $[0]_8$ layup.**
- In this case, the **wet-laminated $[(45/0)_2]_s$ laminate reached 72 %** of the **tensile**, **59%** of **compressive** and **74 %** of **flexural strength** of **$[(45/0)_2]_s$ autoclave-prepreg laminate**, ***(Fig. 5****(b-d-f)*).

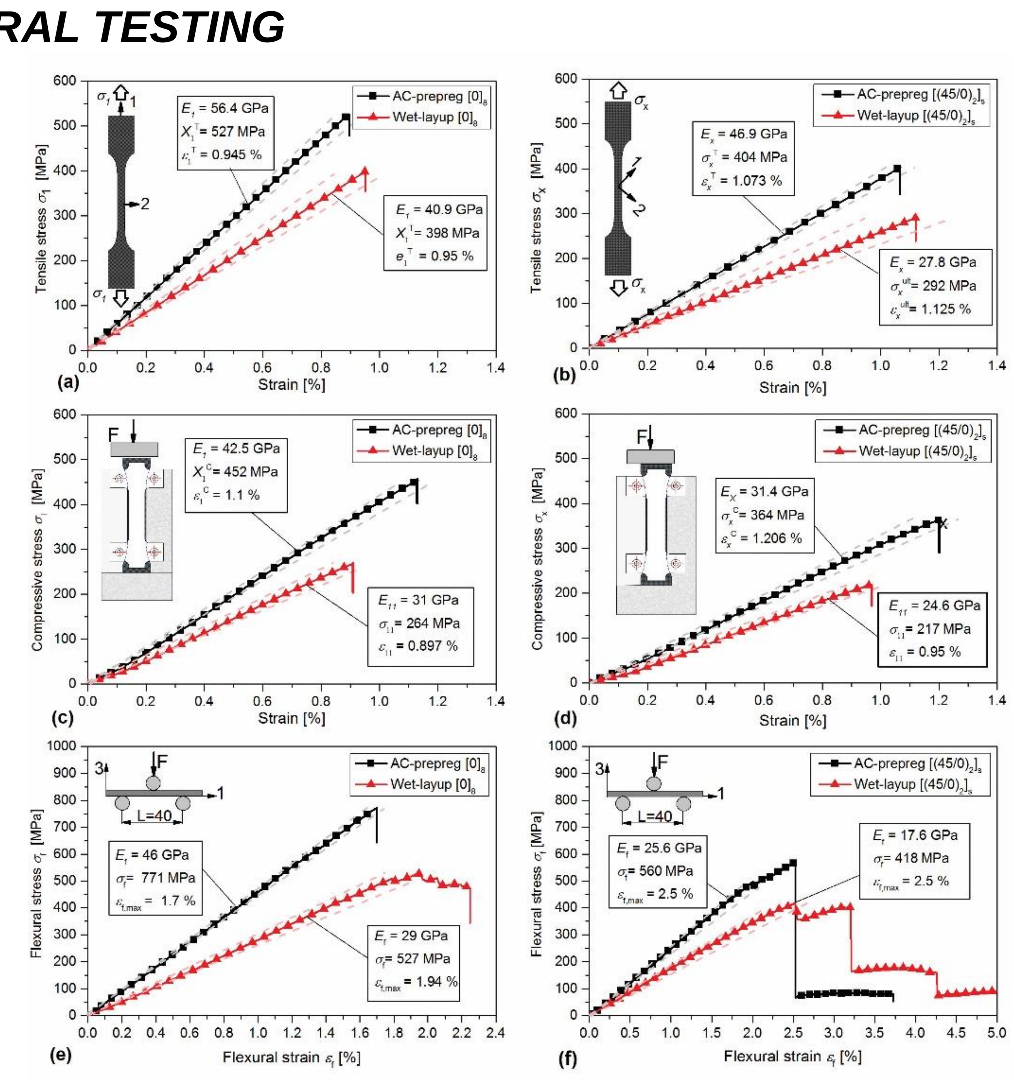

Fig. 5. Stress-strain; (a,b) tension, (c,d) compression, (e,f) flexural tests.

DYNAMICAL MECHANICAL ANALYSES (DMA)

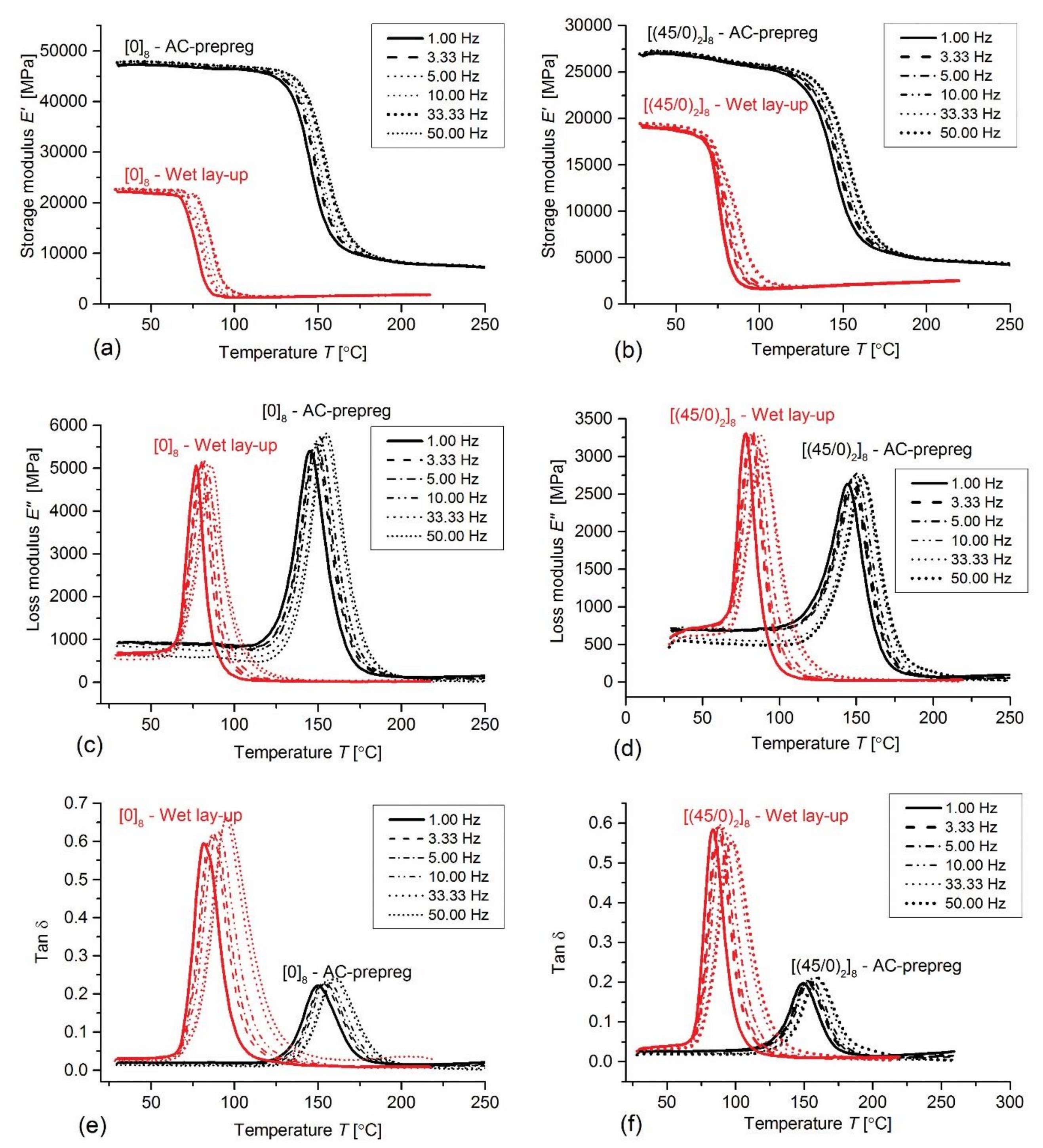

Fig. 6. Storage modulus $E'(T)$, loss modulus $E''(T)$, $\tan\delta(T)$ at testing frequencies 1, 3.33, 5, 10 and 50 Hz.

- The **storage modulus** *E* ' **varies significantly** with the **manufacturing technology** *(Fig. 6a-b)*.
- **Increase** in **storage modulus of autoclaved prepreg laminates -> higher fibre content** (rule of mixture) and a **decrease with the** incorporation of ±45° **plies in $[(45/0)_2]_s$** stacking sequence
- **Autoclave-processed** specimens have **lower damping tanδ throughout the entire temperature range,** with **much lower peak-damping than wet-layup specimen (0.2 vs. 0.6),** ***Fig. 6****c-d.*

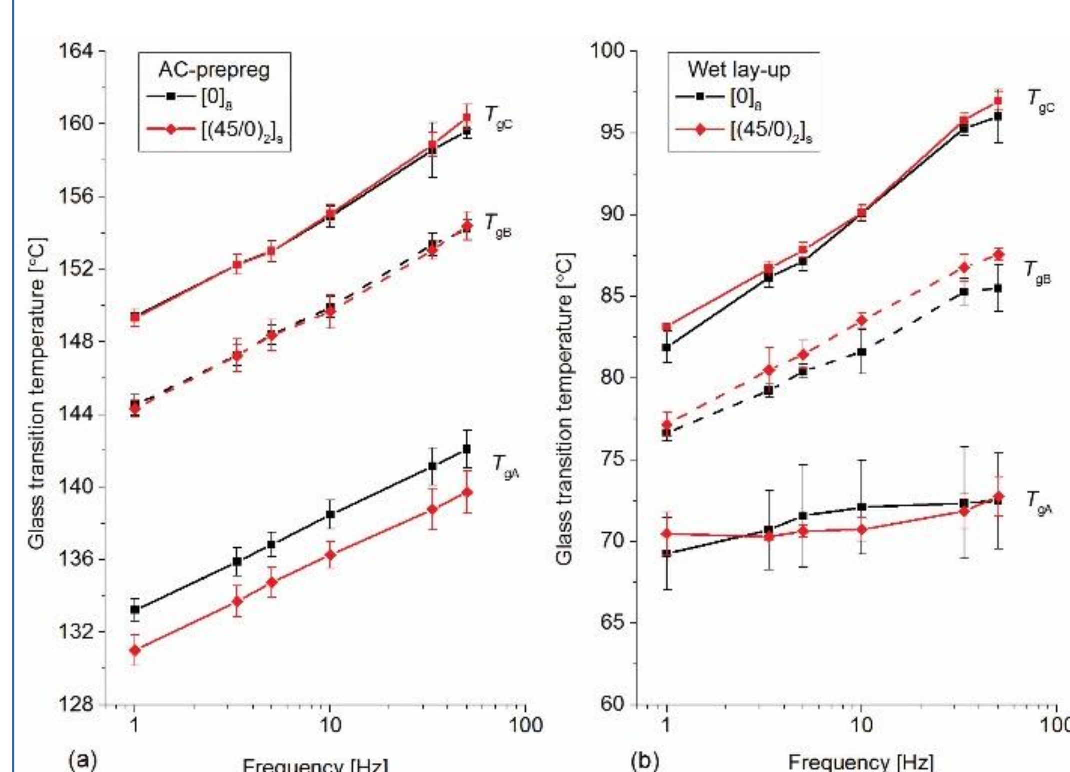

Fig. 7. *Glass transition temperature as a function of testing*

- **The glass transition temperatures T_{gA}** (from storage modulus), **T_{gB}** (from loss modulus curve) and **T_{gC}** (from tan *δ* curve) **increases with frequency of testing.**
- **T_g increased** between **2-14°C *(wet layup)*** and **8-11°C *(autoclave prepreg)***
- **T_{gA} of the wet layup laminate** is the **same as of epoxy** MGS 285 ->**70.2°C**

CHARPY IMPACT TOUGHNESS

- **Higher impact energies** with **wet lay-up specimens** (effect of epoxy resin with lower T_g)
- **Obvious effect** of the **stacking sequence** and **production** process-> **higher toughness** with **quasi-isotropic $[(45/0)_2]_s$ & wet-lay-up**
- With additional/newly prepared **$[\pm45]_8$** specimens the **highest impact energy** has been absorbed & **samples** were **visually undamaged.**

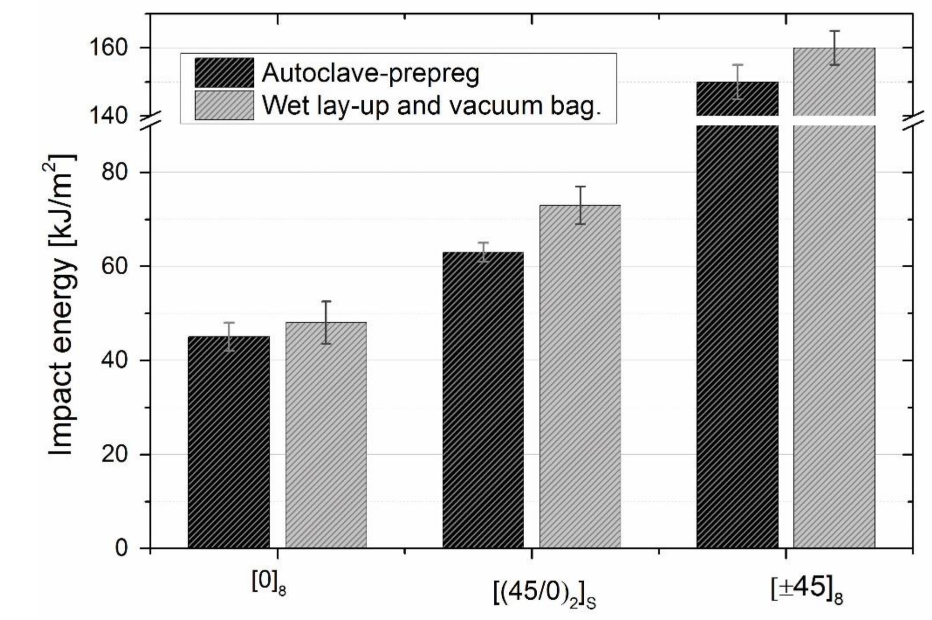

Fig. 8. Charpy un-notched impact energy; flatwise test (ISO 179-2:1997)

CONCLUSIONS

- The **autoclave processed** Torayca/ET445 **laminate** exhibit **significantly higher tensile, compressive and flexural strength** (between 24-42 %) **than wet lay-up** laminate specimens.
- Contrary, **autoclaved laminate** exhibit **lower Charpy impact fracture energy**, due to increased higher brittleness of epoxy system in prepreg, **with higher T_g transition**. The **incorporation of ±45° plies increases the fracture energy** regardless of the manufacturing technology used.
- **DMA multi-frequency analyses** between 30-220°C **confirm** the **storage modulus glass transition influence by the frequency of the test**. Frequency **increase from 1 Hz to 50 Hz**, **increases** the glass transition temperature-***Tg*****, up to 14 °C**. **Energy loss** through damping tanδ **is significantly higher** (*over complete T and f range*) in **wet lay-up specimens** due to lower fibre content.

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