# Developments in ArmaFORM PET core materials for structural sandwich in marine applications

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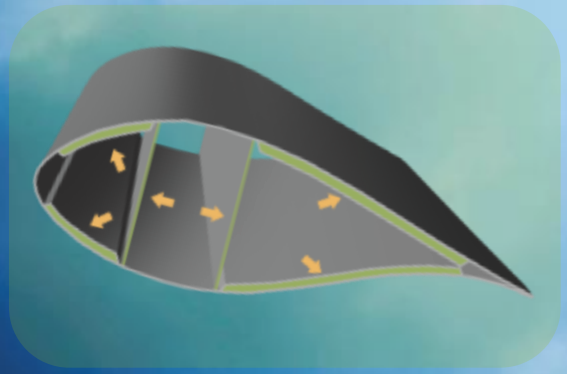
**GM Technical Service**

**Armacell**

**ArmaFORM PET used in > 60.000 wind turbine blades globally.**





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# Russian Orthodox Cathedral
# Paris, France

**ArmaFORM PET used for the 5 gilded domes, coated with 24 karat gold.**


ArmaFORM PET used in the bodywork of (food and delivery) 3.5 trucks.
GRP panels made by Polyfont.

# Agenda

1. **Armacell – the company**
   Facts & figures

2. **ArmaFORM PET – the product**
   Production process
      Quality control
   Product family
      PET GR: Armacell‘s r-Pet technology
   Product properties
      Fatigue
      Temperature stability
      FST

3. **ArmaFORM PET –** Marine
   Cost out using GR grade
   High density GR grade

4. **Conclusions**



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# Armacell

approx.
**3,000**
employees worldwide

25 production facilities in 16 countries on 4 continents

Headquartered in Luxembourg with regional HQs in EMEA, Americas and APAC

total net sales of € 560 million in 2016

## TWO BUSINESS DIVISIONS

### Advanced Insulation

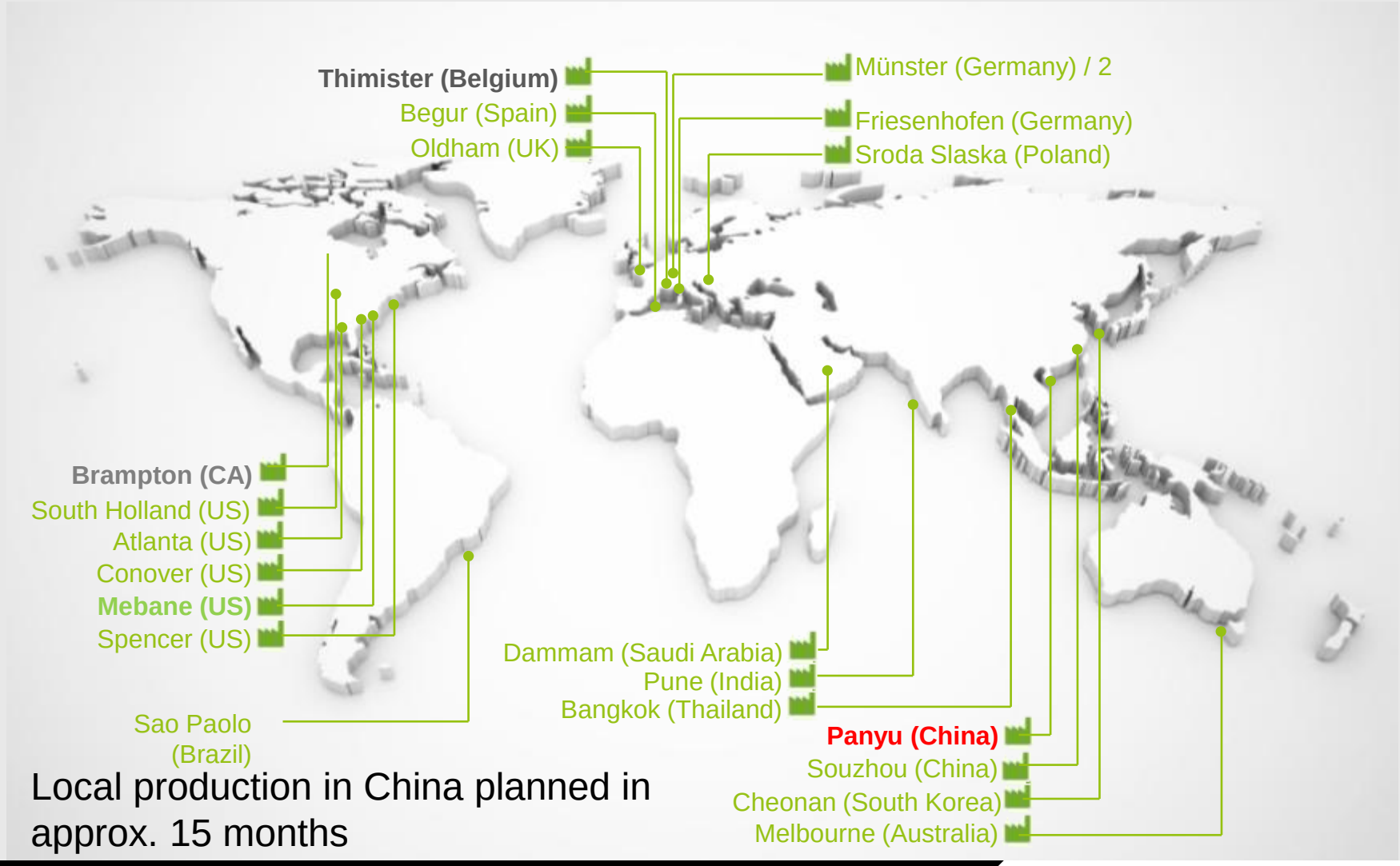
develops flexible foam products for insulating mechanical equipment in markets where energy distribution is required.

### Engineered Foams

develops custom-made high-performance foams used in wind energy, transportation, safety, and sports & leisure markets.

### PET Foams

# Armacell worldwide: 23 production plants in 13 countries on 4 continents




Local production in China planned in approx. 15 months



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**1940s:** long-grain **balsa** with plywood skins used in British aircraft: „Mosquito“

**1960s:** end-grain **balsa** used for GRP yachts.

**1970s: PVC** used for GRP boats: “HSV Viksten”.

**1980s: SAN foam** as *the* new core for Marine application.

**1990s: PVC foam** used in first trains and volume blades of wind turbine market.

# ArmaFORM PET® - huge development potential

**2006**: Launch of **ArmaFORM® PET.** Qualified as foam core in wind turbine blades.

**2009: 2nd generation ArmaFORM® PET** with significantly improved technical properties.

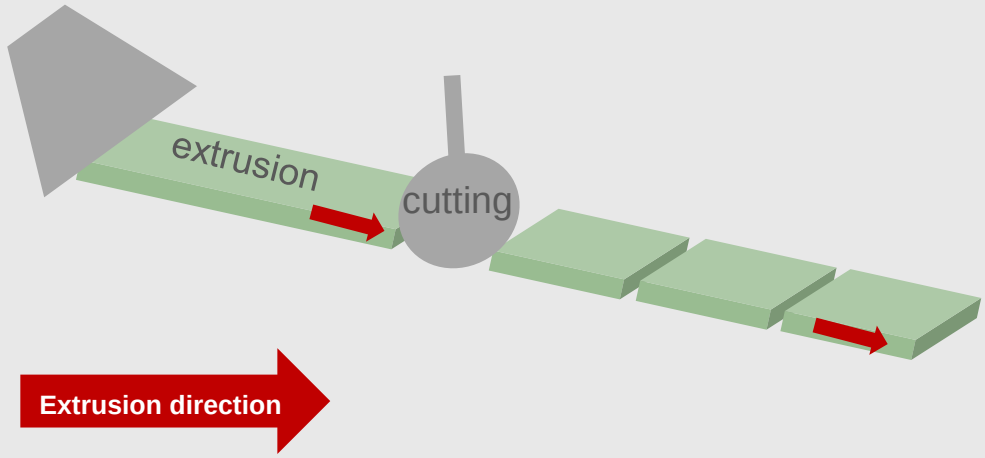
**2010**: **ArmaFORM® PET GR**: the 1st PET foam core based on post-consumer PET.

**2012**: **ArmaFORM® PET FR** with superior FST properties for B&C and railway industry.

**2017**: **ArmaFORM® PET GFR**
- >60.000 wind turbine blades
- ….

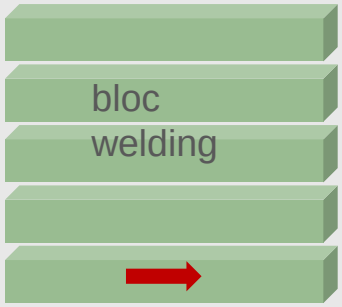
# and continuation of success!

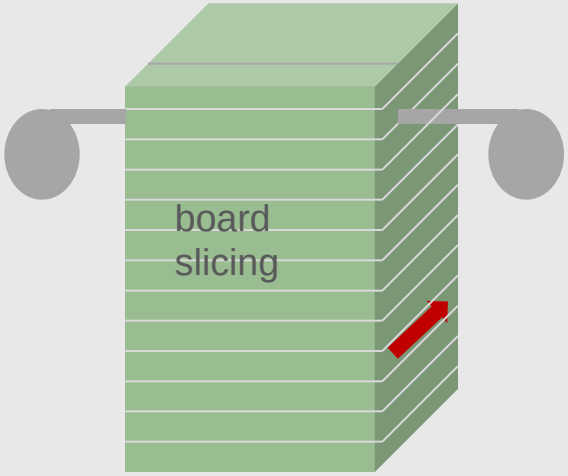
# ArmaFORM® PET Core – the production process




**Extrusion direction**

**PET/E** (extruded)




**PET/W** (welded)

# ArmaFORM® PET Core – the product family

**ArmaFORM® PET: the ideal combination of light weight, strength and durability!**

## PET FR

### fire retardant

- NF F16-101
- DIN 5510-2
- EN 45545-2

**65-150 kg/m³**

Best-in-class fire properties … for application with stringent flame, smoke and toxicity requirements. Will be replaced by GFR grade..

## PET GR

### highly ecological

- less $CO_2$ emission
- less energy consumption

**70-320 kg/m³**

Made 100% of post-consumer PET … for use in environmental sensitive concepts.

**Tailor-made** with: scrim – grid scored – grooved – double contoured - perforated

# ArmaFORM® PET GR ...

… the ‘green‘ among foam cores for the composite industry!



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# Armacell‘s patented r-PET technology


Armacell has spent years of intensive research to develop a process technology that allows to produce **consistent foam qualities from 100% post-consumer PET.**


**49%** end up on **landfills** or waste our oceans.

**15%** mainly to incineration or **landfill** because of impurities.

**36% recycled** to new bottles, textiles etc.

* source: www.pcipetpackaging.co.uk



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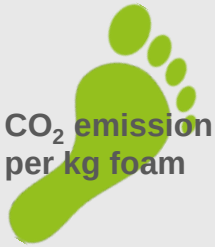
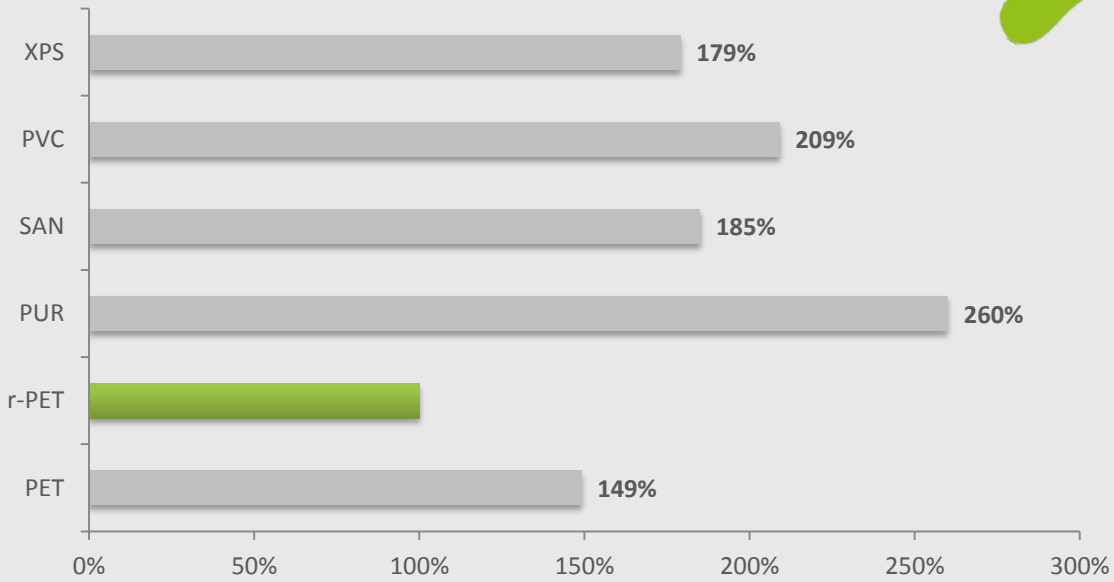
# PET Core – eco balance




Source: SimaPro Database 7.3.0; method: CML 2001

Global warming potential (GWP) or carbon footprint – measures the potential global warming impact of a process in $CO_2$ equivalents of greenhouse gases.



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# ArmaFORM PET – product properties

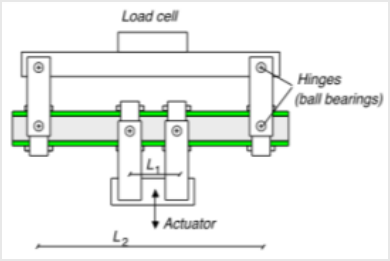
- Excellent damage tolerance
- **Outstanding fatigue resistance** (threshold > 60%) for maximum lifespan
- Excellent long-term thermal stability
- Closed cell: limited water & resin absorption, no corrosion & degradation
- **High processing temperature of 150°C** (short-term up to 180°C)
- Limited density variation (<5%)
- Good screw retention & bonding
- **Easy processing with most types of resin & production methods**
- Easy to shape by thermoforming (3D)
- **100% recyclable**
- **Best-in-class FST properties**
- Superior mechanical properties (high compression strength & shear modulus)
- Very good thermal conductivity (PET/W 0.034 W/mK, PET/E 0.028 W/mK)
- Certified:

# ArmaFORM GR grade; Fatigue testing GR115

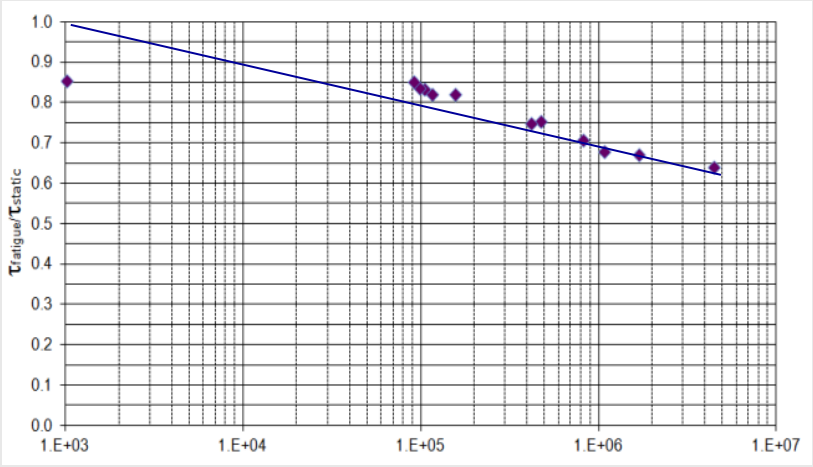
ArmaFORM PET core performs much better than PVC core in fatigue:

Even though the static properties in the data sheets of PVC core might be higher … when fatigue comes into play the actual useful strength properties are better for ArmaFORM PET:

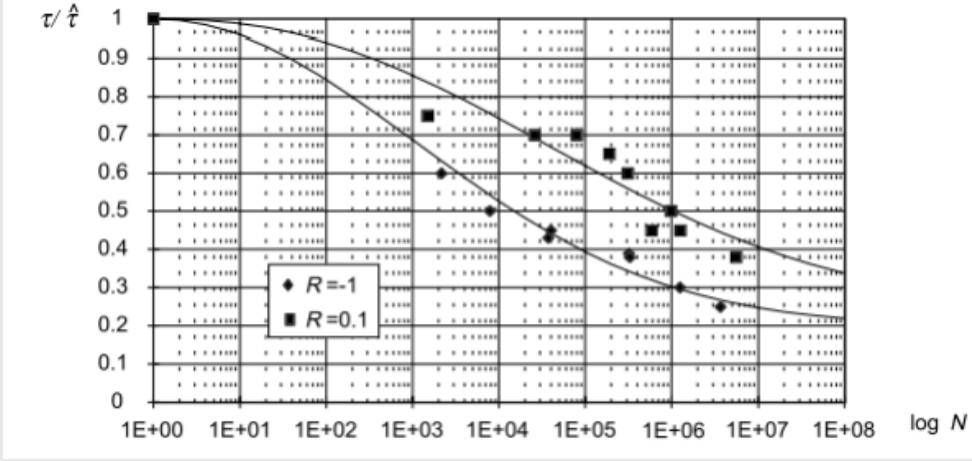
And properties do not degrade before breaking




| Core | R = -1 | R = 0,1 |
|---|---|---|
| PVC | 20% | 30% |
| ArmaFORM PET | 45% | 60% |




Graph 2 Fatigue performance for PVC core



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# ArmaFORM PET – temperature stability

ArmaFORM PET exhibits glass transition temperature **(Tg) close to 75°C**.

Above 75°C crystalline structure arise that acts as static, non-movable system until melting begins at about **240°C (melting point)**.

**Wide range of processing temperatures:**

- e.g. 140°C: allows a process time of days
- e.g. 180°C: allows process cycles of a couple of hours

When cooled down ArmaFORM PET core maintains its original properties.

**What is about PVC core foam?**

No crystalline structure. Mechanical properties change drastically when Tg is exceeded!

Tg for PVC core is 83°C

Processing temperature limited:

Standard PVC: ~ 85-90°C

High temperature PVC: ~ 130°C

No recovery of properties when cooling down ones the critical temperature has been exceeded.



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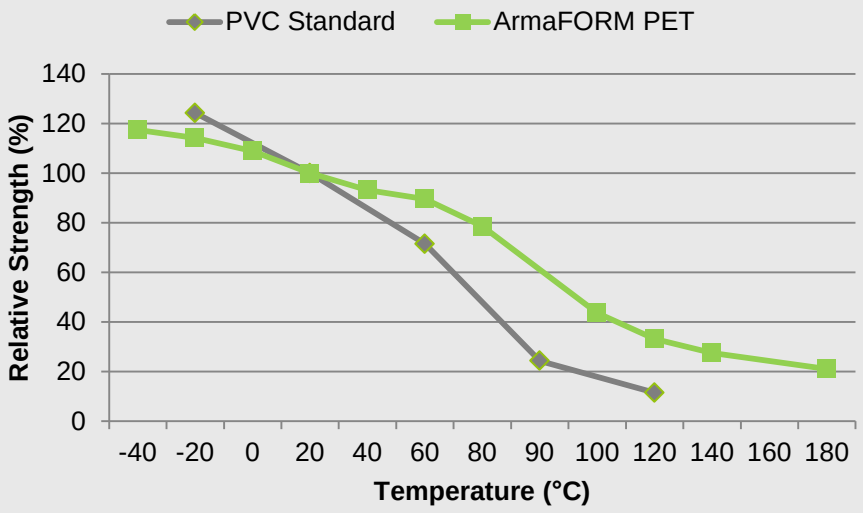
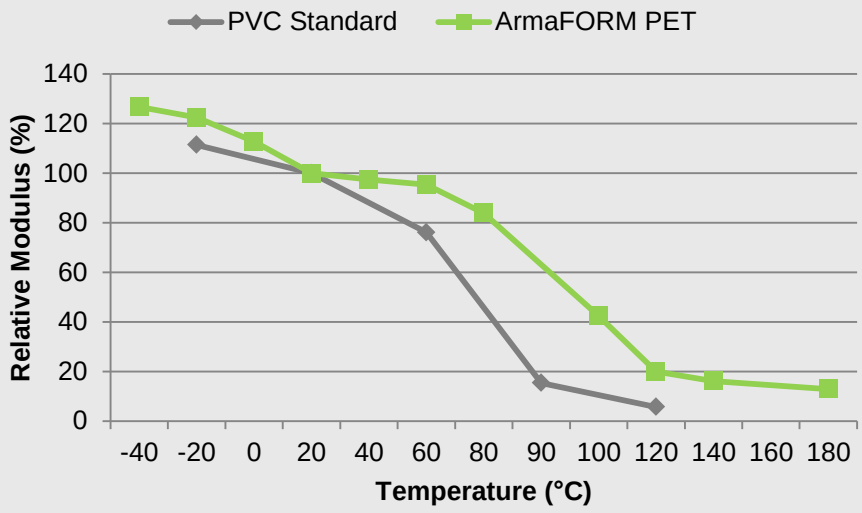
# ArmaFORM PET – temperature stability

After the Tg is exceeded (80-100°C) PET core loose mechanical properties more rapidly until the crystalline network provide a cushion effect. Above 180°C the crystalline network also starts to melt and the core softens even further.

## Relative Compression Strength




## Relative Compression Modulus




- Stiffness and strength properties for PET core are very stable within widely used operating temperatures.
- Maintains properties at elevated temperature significantly better than PVC:
  120°C: approx. 33% for PET core
  120°C: approx. 11% for PVC core

Compression strength (nominal)

**PVC80:**
1,4 MPa * 11% => 0,15 MPa

**GR80:**
0,95 MPa * 33% => 0,31 MPa

# Armacell –FST properties

EN 45545 FST testing

Summary of test results EN 45545-2: 2013 requirements set R10:
Panels with Phenolic skin both AC 80 and Nomex HC are HL3 (highest possible i.e. All applications possible including metro/subway trains)

| SAMPLE 2982/83/84 Phenolic matrix with PET core (AC 80 core) | | | |
|---|---|---|---|
| **Standards** | Parametre | Results | Final classification |
| **ISO 9239-1** | CHF (kW/m²) | 10,9 | HL3 |
| **ISO 5660-1** | MAHRE ((kW/m²) | 0 | HL3 |
| **EN ISO 5659-2** | Ds max | 4 | HL3 |
| | ITCG | 0 | HL3 |

| SAMPLE 2979/80/81 Phenolic matrix with nomex core | | | |
|---|---|---|---|
| **Standards** | Parametre | Results | Final classification |
| **ISO 9239-1** | CHF (kW/m²) | 10,9 | HL3 |
| **ISO 5660-1** | MAHRE ((kW/m²) | 2 | HL3 |
| **EN ISO 5659-2** | Ds max | 58 | HL3 |
| | ITCG | 0 | HL3 |

PET is even better than nomex honeycomb in smoke and toxicity

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# High density PET

Increased interest in high density PET core, 200 and 250 kg/m3.

Traditional applications are for inserts and areas with creep problems, transoms etc.

Now we also see an interest in replacing balsa from other industries like wind blade applications, why??

Balsa has several drawbacks as for quality and moisture uptake.
One blade producer need to decrease the number of repairs, too much time and cost lost.
Another can not assure that the balsa does not exceed the moisture level set in the quality system.

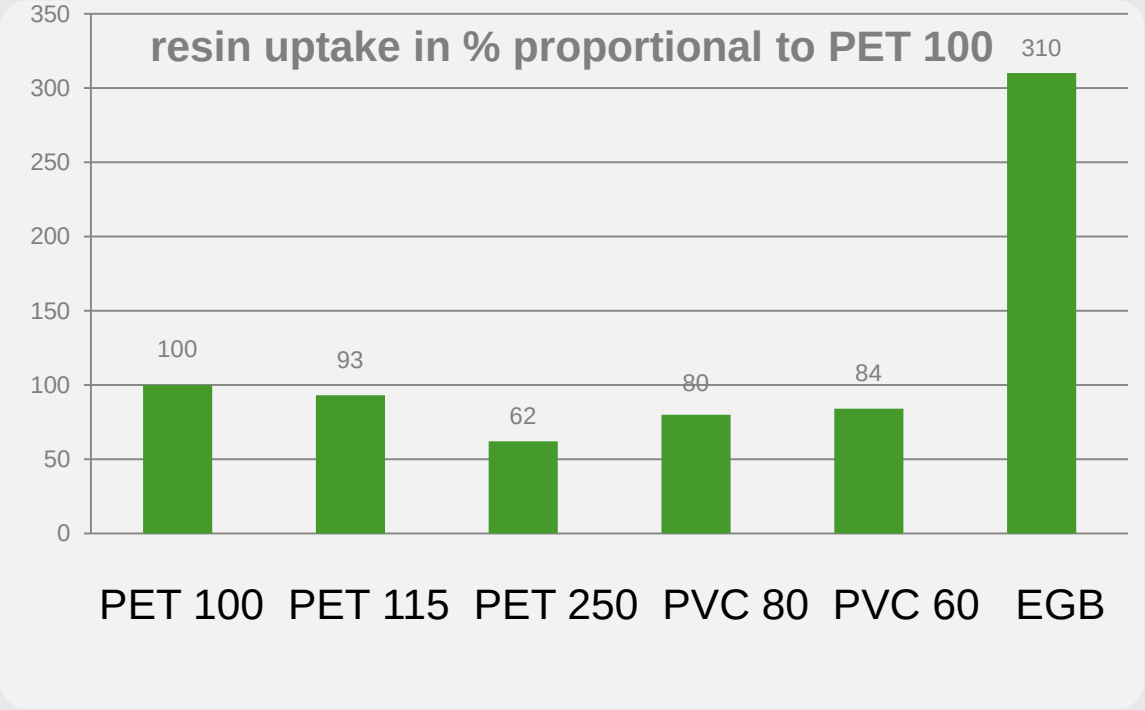
# High density PET

Now we also see an interest in replacing balsa, why?

Balsa has fantastic properties on paper but testing in 4-Point Bending show something else. GR 250 has clearly higher shear strength when tested in 4-PB than infused balsa beams

# High density PET

Now we also see an interest in replacing balsa, why?




The high resin uptake for balsa will increase actual density to > 250 kg/m3 in most cases (thickness dependant).

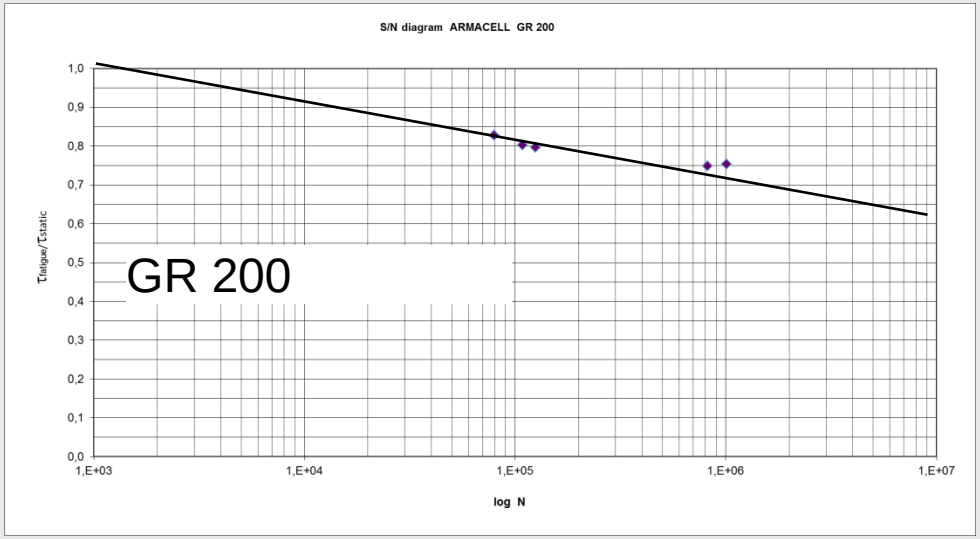
So it is actually possible to infuse panels with better properties and lower weight using PET 250 than EGB

# Fatigue testing on GR 200 at KTH

CORE SHEAR FATIGUE TEST

Correlation between the GR 200 and previous testing on GR 115 and other grades are extremly close and again confirm that results are density independant if normalised.

The fatigue threshold level is >60% and GR grade easily exceed the DNV GL requirement on m>10, for GR115 m=16,9 and testing on GR200 indicate at least this number.



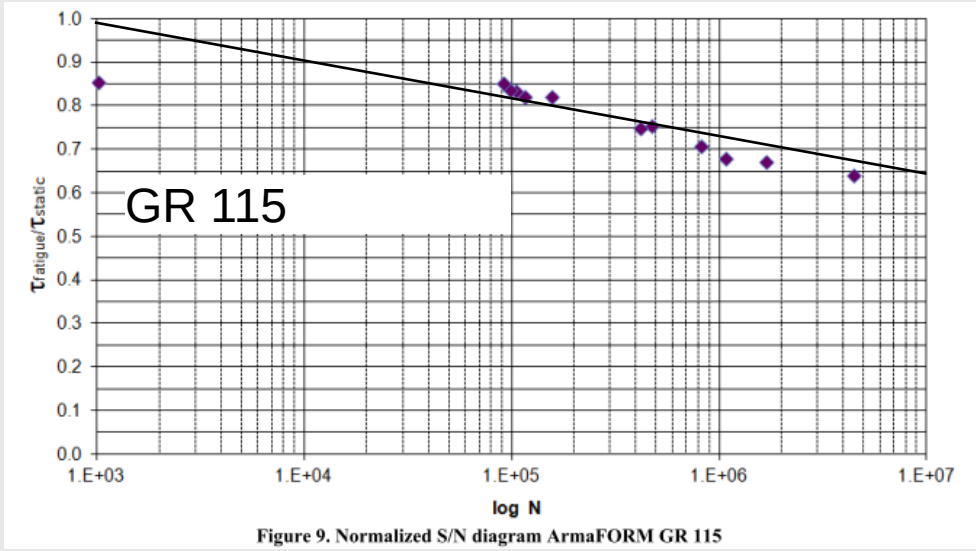




Figure 9. Normalized S/N diagram ArmaFORM GR 115



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# Summary ArmaFORM GR grade

Advantages for PET cores vs. Other structural core materials.

- Great thermal stability
- Excellent fatigue properties
- Good FST properties with very low smoke and toxicity
- Lower density variation and flat sheets
- Excellent processing stabilty
- Possiblity to recycle the core, scrap from kitting today and the rest after the end of the blade life cycle.
- A core solely based on recycled PET material
- Possibility to thermoform also thick and complex shaped sections, saving resin, weight and cost.

- Best cost to performance ratio, >15% saving compared to other PET.
- Local production in Americas now and China “soon“

**Thanks for your attention… when do you start using ArmaFORM PET?**

**Questions?**