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DEVELOPMENT OF DURABLE TRAIN FLOOR COMPLIANT WITH EN 45545-2

¬ Introduction

The work was carried out to evaluate the suitability of different combinations of core materials and resin system for a train floor. Current train floor designs are based on either end-grain balsa core or phenolic honeycomb core but both solutions have drawbacks that have made floor service life shorter than expected.

The new floor concept has to meet relevant standards, including the new European EN 45545-2 FST norm. The focus has been on designing a lightweight floor system with high damage tolerance to give a long service life and trouble-free maintenance.

Six different material combinations were manufactured using two different resin systems, fire retarded epoxy and phenolic, and a total of four different core materials, end-grain balsa, phenolic honeycomb and ArmaFORM® PET in 80 and 100 kg/m³ density. Initially the panels were tested undamaged in compression, using a 4-point bending test jig. Impact testing was performed to establish a barely visible damage to the most resilient panel. All panels were subjected to impact with this energy load in order to produce damage to the upper skin and core. Again, a static 4-point bending test was performed to establish strength reduction and finally 4-point bending fatigue testing was initiated to evaluate the influence of dynamic loading. In addition the FST performance was evaluated according to the EN 45545-2 test standard. This relatively new strict standard requires the full sandwich structure to be tested.

¬ Manufacturing of floor panels

Six different panels were manufactured, using two different resin systems, fire retarded epoxy and phenolic, and a total of four different core materials as per Table 1 on the next page. The target thickness for the panels was 19 mm with a core thickness of 15 mm and skins of 2 mm on each side. The manufacturing method was wet preg with vacuum consolidation due to the high level of filler and thus viscosity, especially for the epoxy system.

The epoxy panels were heavier and thicker than the corresponding phenolic ones. Lightest of all panels was ArmaFORM® PET in 80 kg/m³ with phenolic resin and heaviest was the end-grain balsa panel (+25%) with phenolic, unsurprisingly considering the much higher core density of balsa. Interestingly, PET cored panels are always less in weight than the Nomex honeycomb cored panels.

¬ Static 4-point bending test

A static 4-point bending test according to the ASTM C-393 method was performed to establish the strength of the beams as a function of the core

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Panel Type		Core Type & Thickness	Panel Weight (kg)	Panel Thickness (mm)	Resin	Process
Phenolic skins 2 mm each side	2903	Nomex honeycomb 15 mm	8.3	17.9	GP 5022	Vacuum bagged
	2904	ArmaFORM PET (80 kg/m³) 15 mm	7.75	18.9	GP 5022	Vacuum bagged
	2905	End-grain balsa 15 mm	9.6	19.5	GP 5022	Vacuum bagged
Epoxy skins 2 mm each side	2908	Nomex honeycomb 15 mm	9.4	18.5	Resoltech 1090 FR	Vacuum bagged
	2906	ArmaFORM PET (80 kg/m³) 15 mm	8.86	19.2	Resoltech 1090 FR	Vacuum bagged
	2907	ArmaFORM PET (100 kg/m³) 15 mm	8.8	19.3	Resoltech 1090 FR	Vacuum bagged

Table 1: Material configuration, weight and thickness for the 6 different panels produced.

material in the different configurations. Initially it was intended to test three beams of each type but as most results had little scatter only two of each was tested in the end.

Results are presented in Table 2 with the shear stress in the core and the load normalized for the panel weight to give a comparative figure. Balsa performs best but with the highest weight. Of the other cores Nomex honeycomb performs well with epoxy resin but not with phenolic resin. The

Sample	Load at break reference (N)		Load at break reference (N)	Core	Shear strength, original (MPA)	average normalized N/kg
2903	1310	1400	1355	Nomex HC	0.75	163.25
2904	1560	1210	1385	PET 80 kg/m³	0.77	178.71
2905	4000	3780	3890	Balsa	2.16	405.21
2906	1170	1150	1160	PET 80 kg/m³	0.64	130.93
2907	1610	1590	1600	PET 100 kg/m³	0.89	181.82
2908	2280	2060	2170	Nomex HC	1.21	230.85

Table 2: Load at break and shear strength for 4-point bending test.

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ArmaFORM® PET foam cores have shear strength values well in line or over data sheet values.

¬ Impact testing

A simple jig was devised where a cylindrical 2 kg weight with half sphere end cap was guided in free fall mode to impact the beam in the desired location, see figs. 1 to 3. Initial testing was performed to establish a barely visible damage to the most resilient panel.

Fig. 1: test jig

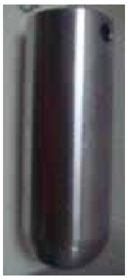

Fig. 2: 2 kg weight

The weight was dropped from a height of 1.5 metres, thus yielding impact energy of approximately 30 Joules.

The impact location is between the outer supports as indicated in the area of constant shear stress in the core when testing in 4-point bending mode, see fig. 3. The beams were tested for two different boundary conditions. At first the beams were fully supported on the back side when impacted, resting on a stiff aluminum profile.

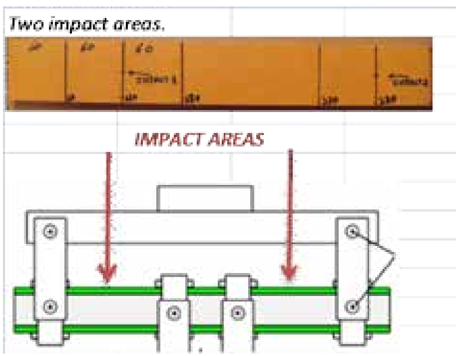

Fig. 3: impact areas

The impact yielded very little visible damage on the ArmaFORM® PET cored beams, slightly more visible damage on the honeycomb cored beams and, surprisingly, the most visible damage on the balsa cored beam, see figs. 4 to 12.

Figures 4 and 5 show Nomex honeycomb beam (2903) after the impact and 4-point bending test. The impact location on the sandwich top surface is marked. Note the **permanent deformation and damage to the skin**. Figure 5 shows typical **buckling damage** to the honeycomb core cell walls under the impact location.

Fig. 4

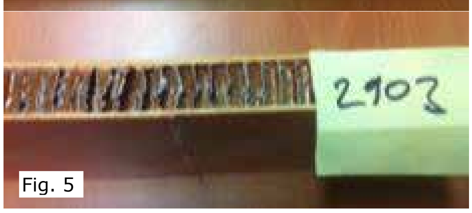

Fig. 5

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Figures 6 and 7 show ArmaFORM® PET 80 kg/m³ cored beam (2904) after the impact and 4-point bending test. The impact location on the sandwich top surface is marked. Note the **damage to the skin but no permanent deformation**. Figure 7 shows no visible damage under the impact area.

Fig. 6

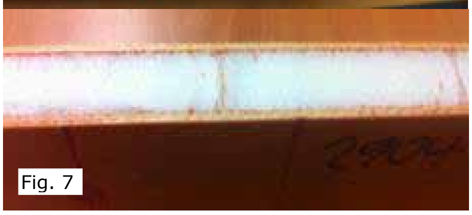

Fig. 7

Figure 8 shows end-grain balsa beam (2905) after the impact and 4-point bending test. The impact location on the sandwich top surface is marked. Note the **significant indentation and delamination** around the impact area.

Fig. 8

Figure 9 shows ArmaFORM® PET 80 kg/m³ cored beam (2906) after the impact and 4-point bending test. The impact location on the sandwich top surface is not marked but can be see as a whitening in the skin due to matrix crazing. **No permanent deformation**.

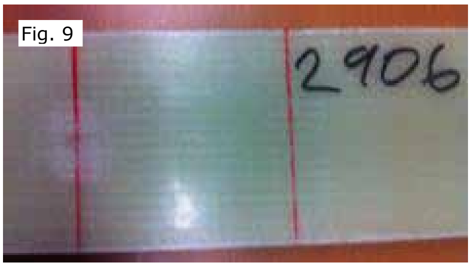

Fig. 9

Figure 10 shows ArmaFORM® PET 100 kg/m³ cored beam (2907) after the impact and 4-point bending test. The impact location on the sandwich top surface is marked and can be seen as a whitening in the skin due to matrix crazing, but less than on beam 2906. **No permanent deformation**.

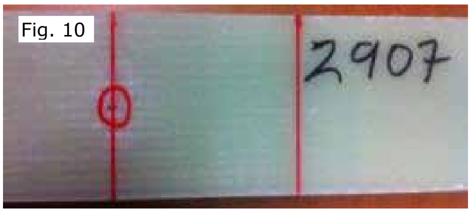

Fig. 10

Figures 11 & 12 show Nomex honeycomb beam (2908) after the impact and 4-point bending test. The impact location on the sandwich top surface is marked and can be seen as a **whitening in the skin** due to matrix crazing (fig. 11). Further whitening is noticed where the beam has collapsed at the impact location and at the support during the 4-point bending test. Figure 12 shows typical

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buckling damage to the core and **permanent deformation**.

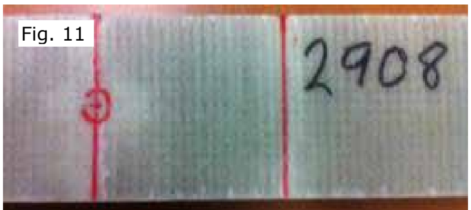

Fig. 11

Fig. 12

One alternative can be to not have this fully support boundary condition but instead let the beams rest on edges and deflect a bit when impacted. This can give different damages depending on the core material used. This was also tested but due to the configuration of the jig it was not possible to have a wider distance between the supports than 100 mm. With this boundary condition and the same drop height, all specimens broke with the core failing in shear; examples are given in figs. 13 and 14.

Figures 13 and 14 show end-grain balsa (2905) and ArmaFORM® PET 100 kg/m³ (2907) cored beams after the impact testing with simply supported boundary conditions. Both failed in shear but with very different permanent damage. Balsa beam (2905) has **skin delamination over the whole width** making repair difficult, while ArmaFORM® PET beam (2907) has **very minimal skin damage** which could be repaired by injecting resin.

Fig. 13

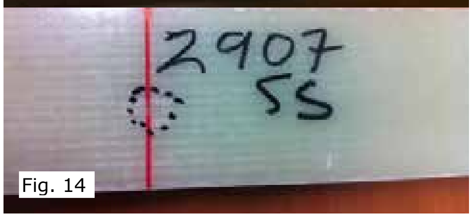

Fig. 14

¬ Static 4-point bending test on impacted beams

After impact, a 4-point bending test was performed on the different beams in the same way as for the undamaged beams, and the results were compared, see Table 3 on the next page.

Only two of the cores had a reduction of less than 20% in failure load, the balsa (but with wider scatter) and ArmaFORM® PET 100 kg/m³. These same two were the same that had the highest shear stress at failure. The Nomex honeycomb core with epoxy resin had the biggest drop in properties, i.e. was the most sensitive to impact damage, it lost almost exactly half its strength. The ArmaFORM® PET 80 kg/m³ cored sample displayed a very similar load level for both resin types, while Nomex

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Sample	Load at break after impact (N) break after impact (N)		Load at break after impact (N)	Residual strength (%)	Drop (%)	Core	Shear strength, impacted (MPA)
2903	892	860	876	64.6	35,4	Nomex HC	0.49
2904	729	769	749	54.1	45,9	PET 80 kg/m³	0.42
2905	3810	2950	3380	86.9	13,1	Balsa	1.88
2906	747	846	797	68.7	31,3	PET 80 kg/m³	0.44
2907	1290	1280	1285	80.3	19,7	PET 100 kg/m³	0.71
2908	1080	1100	1090	50.2	49,8	Nomex HC	0.61

Table 3: Material configuration, weight and thickness for the 6 different panels produced.

honeycomb still performed better with epoxy resin than with phenolic resin.

¬ FST testing according to the EN 45545-2:2013

FST (Fire, Smoke and Toxicity) testing was performed on some of the tested panels. The new European norm for train applications EN 45545-2:2013 was used, as this has started to be implemented from 2013.

EN 45545-2:2013 is now replacing the CEN/TS 45545-2:2009 and was given official status in September 2013. Older national standard within the EU are to be revoked no later than March 2016.

The specific tests for EN 45545-2: 2013, material requirements set R10 / R1:

- **EN ISO 5659-2: 2006** 50kW/m² (R1) and 25kW/m² (R10) Smoke Generation and Toxic Gas
- **ISO 9239-1** Flame spread

Also tested was the **ISO 5660-1** heat release rate (Cone calorimeter method) although it is not strictly needed according to the standard.

Two panels, 2903 and 2904, were tested with phenolic skins and Nomex honeycomb and ArmaFORM® PET 80 kg/m³ core respectively. Both panels passed the test with really excellent results, see Tables 4 and 5. Both are classified HL3 which is

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the highest class, and these materials can be used for all types of trains including metros & subways. Furthermore, the PET cored panel is even better than the phenolic honeycomb, with lower smoke and toxicity values and slightly lower heat release rate.

Sample 2979/80/81: Phenolic skins with Nomex honeycomb core			
Standard	**Parameter**	**Result**	**Class**
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

Table 4: Panel 2903 tested for material set R10 according to EN 45545-2:2013

Sample 2982/83/84: Phenolic skins with ArmaFORM® PET 80 kg/m³			
Standard	**Parameter**	**Result**	**Class**
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

Table 5: Panel 2904 tested for material set R10 according to EN 45545-2:2013

These results also indicate that FR (fire retarded) core material grades will not be needed for trains classified with this new norm, as the core contributes mostly to the smoke and toxicity levels, very slightly to heat release but almost nothing to flame spread.

However testing the fire retarded epoxy skinned ArmaFORM® PET cored panel in the same way did not give equivalent excellent results, see Table 6. Although the panel passed the test, the HL1 classification limits use to train on above-ground tracks only. Fire response and flame spread on the

Sample 2906: Epoxy skins with ArmaFORM® PET 80 kg/m³			
Standard	**Parameter**	**Results**	**class**
ISO 5660	MAHRE (kW/m²)	38	HL3
ISO 5659-2	Ds max	331	HL1
	ITCG	0.025	HL3
ISO 9239-1	CHF (kW/m²)	10.9	HL3

Table 6: Panel 2906 tested for material set R10 according to EN 45545-2:2013

epoxy skin is still good but smoke generation is much higher than for the phenolic skins and this lowers the classification to HL1.

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¬ Outlook: further testing

The panels will now be tested for fatigue after impact to see how crack growth affects the different material combinations. This will be carried out on the impacted panels to allow the influence on the service life to be predicted. It is however likely that a similar relative performance to 4-point bending after impact will be identified.

It would be interesting in the future to perform FST testing according to EN 45545-2 for other material sets. The most interesting combination is with the phenolic resin being lighter and with better FST performance together with the PET foam core. The most used material set is the R1, vertical interior surfaces, so this should be tested in that case.

¬ Conclusion

The project was carried out to demonstrate that ArmaFORM® PET foam core could be used in a composite sandwich floor system as it has sufficient impact resilience and also meets the new European FST standard EN 45545-2:2013.

Testing showed that the ArmaFORM® PET core was more damage-tolerant and had better FST results than the honeycomb solution.

A composite sandwich floor with end-grain balsa core is even stronger, but is also heavier, less damage-tolerant and has worse FST performance.

The best solution from point of view of cost, weight, FST and LCA aspects would thus be a ArmaFORM® PET foam core in the composite sandwich train floor and other train applications.

Note: For detailed test results and certificates please contact us.

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