The new Klang Valley Mass Rapid Transit Scheme is the largest public transport project in Malaysia. The first branch of this line is scheduled for completion in 2017 with an initial fleet of state of the art automated trains from Siemens. Designed for both tunnel and elevated operation, the interior components required a composite solution that would meet the highest FST requirements, while providing a light weight and robust interior.

This case study presents a composite manufactured train seat developed in collaboration between Gurit and dk Composites (Malaysia) for the KVMRT project (Klang Valley Mass Rapid Transit).

The Siemens ‘Inspiro’ Metro train was selected by Mass Rapid Transit Corporation to form the fleet of 58 new trains for Line 1 of the Klang Valley Mass Rapid Transit (KVMRT) network, which runs from Sungai Buloh to Kajang in the greater Kuala Lumpur area. Line 1 is to form the central spine of a larger rail network serving the Klang Valley region. It will have 31 stations serving over 1.2 million people, with an estimated 440,000 passenger journeys every day.

The line is 51 km long with over 9.5km of tunnel sections. The train features state of the art automation and is both driver and conductor-less. The train is designed for tunnel and elevated operation and as such had a high fire protection requirement according to BS 6853 Cat 1a together with maximum heat release according to EN 45545 HL3.
Due to the complexity of the geometry and the structural performance to the total system being dependent of each of the components and more significantly their attachment details, the structure was verified using and in-depth finite element analysis.

The ‘Inspiro’ series of Siemens trains are also designed for optimised energy consumption and to be a low maintenance solution. The design for the trains known as ‘guiding light’ was completed by Designworks USA, and reflects modern Malaysia as a dynamic and technological country. This included light blue colouring to the interior and for the seating elements which were cantilevered off the wall with energy efficient LED lighting from underneath.

dk Composites undertook fire testing to establish which materials would meet the Cat 1a and HL3 FST requirements. The solution that was selected by dk Composites was a Gurit Phenolic Resin PH 840 combined as a prepreg form with E-glass reinforcements, combined with Gurit® G-PET™ FR core materials to make a light weight and cost efficient composite solution. Gurit’s Engineered Structures team provided the engineering design and verification of the composite seats and leaning bars, aluminium support structures and bolting details that form the seating system.

Engineering Design and Analysis

In addition to the FST requirements, demanding structural requirements were placed on the seats to ensure passenger safety and also longevity of the seating system. The basic design called for a moulded composite seat bolted to a aluminium cross bar, which was internally supported by a cantilevered bracket that attached to the side wall of the stainless car body. The upper edge of the seat is also attached with a light weight bracket. The seats are designed to be assembled in multiple configurations from single seat to 7 seat configurations.

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The composite seat itself is constructed from two components, the sandwich seat shell, and monolithic tophat stringers which are adhesive bonded to the under side using Gurit Spabond 340LV Epoxy Adhesive.

The full seating system also incorporates a leaning rest bar (also in Phenolic composite, with aluminium brackets) and a pair of folding seats per train which have a composite seat on a steel frame.

As well as a requirement of ensuring the design was both strong and stiff enough to meet the design load cases there was also a desire to ensure that the composite and metal structure were well optimised. This need for optimisation was two fold, firstly with low weight being desirable for energy efficiency of the train in operation, and secondly it is important to optimise materials consumption to minimise production costs in terms of both labour and material consumption without compromising the strength of the system. For example a solid laminate phenolic
solution would have meet FST and structural requirements, but would have been more expensive to fabricate, and heavier than a sandwich structure.

As a result a foam cored solution was developed. Design of sandwich structures requires careful attention to the relevant failure modes, including fibre and resin failure modes, core related modes such as core shear but also skin wrinkling and shear crimping modes in and around highly loaded areas. The analysis was completed with Altair Hyperworks suite of software, and using Gurit’s in house tools and processes specific to composite materials.

The composite seats were modelled using QUAD 4 shell elements, with each seat model was made up of 34000 elements. Initially the mounts were considered as rigid as providing a conservative strength result at the fixing points. The performance of the seven seat unit was then used to optimise the structural requirements on the metallic structure, as this layout featured the highest ratio of seats (and therefore passenger loads) to cantilever brackets. As such it defined the most severe load case for the metal work and was also used to confirm the overall displacement of the assembled system.

Loads were extracted from this model for calculation of all bolted and bonded joins. The analysis included three basic load types:

- **Static Load cases** - featuring points loads over various areas designed to simulated every day and also accidental and misuse (vandalism) load cases, with deflection limits seat for each, and in every day load cases a requirement for no permanent deflection of the assembly.

- **Dynamic load cases**, as defined by EN 12663-1 simulating loads expected to be experienced during the active life of the structure again without failure, excessive deflection or permanent deflection. This included load cases up to 3G.

- **Fatigue Load cases**, as defined be EN 12663-1 to ensure that the parts had sufficient structural performance to perform over the life of the trains without degradation, particularly around highly loaded parts of the structure.

More than 60% of the seat is made of a sandwich structure (composite skins separated by a lightweight structural core) bringing a significant advantage against standard product: weight saving goes beyond 50% when compared to a fabricated aluminium plate seat and 30% when compared to the originally foreseen solid skin GFRP seats shells.

**Material & Process**

When working with phenolic resin, there are in principal two options: wet or prepreg resins. While wet laminating never was an option for dk Composites due to the extremely high Formaldehyde content of those resins, which causes an unacceptable health hazard for the workers, modern prepreg resins contain no Formaldehyde.

With the PHG 840 phenolic prepreg from Gurit, a resin system is available and selected, that not only requires no other safety precautions than those being standard in the composite industry if good governance is observed, but also provides technical properties close to those of epoxy resins.

Producing almost 10,000 seat shells at a daily production rate of 20-30 units combined with the depth of the geometry, is giving importance to the tooling as well as the construction process. Taking advantage from the out-of-autoclave properties of the PHG 840 prepreg system, a vacuum consolidated prepreg process, with which dk Composites is highly familiar with, was selected, using cost efficient GFRP tooling.

The advantages of press application, such as cure times as low as 10 minutes as well as less work during lay-up and finish still did not justify the high initial set-up cost for a heated press and matched metal moulds.

dk Composites had used its vast experience in computer based 3D-modelling with the CATIA software and subsequent CNC-milling of the plugs. By considering seat as well tool design together with CNC-programming as downstream operations originating from the fully detailed and assembled digital seat model, it was possible to provide references and datum along the whole process of seat assembly in moulds and jigs with milling accuracy. As a result, means for adjustment, such as oblong holes and floating nuts, could be kept to a minimum, noticeably simplifying the seat design while maintaining interchangeability in service.
Special consideration needed the selection of the tooling resin system, which had to accommodate the low temperature resistance of the plugs as well as a cure of 120°C for the phenolic parts. Based on experiences gained during a previous project, dk Composites selected the epoxy resins and gelcoat from the Gurit T series, using vacuum infusion to fabricate the mould body and wet laminate for secondary support structure.

To meet the build schedule, a total number of 50 GFRP moulds had been commissioned to the production line, allowing for concurrent lay-up and consecutive curing and bonding of a day’s production. Remaining moulds are kept on standby, thus preventing stoppages of the production line in case of mould servicing or replacement is required. Each mould is expected to produce 100 parts over its life span. Additional GFRP tools and jigs are provided for bonding and vacuum supported warm-forming of the core.

**Tooling System**

dk Composites manufactured all of its own composite tooling for this project. They selected the Gurit T series of Epoxy tooling resins and gelcoats. This is an epoxy system specially formulated to make FRP tooling suited for elevated temperature cures such as those required for phenolic prepreg. The system has been formulated with a Tg (glass transition temperature) of 130°C when fully post cured. This ensures maximum surface quality is retained even after repeat cure cycles. To allow thick sections of tooling to be built up rapidly the formulation has low viscosity in hand or infusion capable versions allowing the use of heavy reinforcement layers to quickly build tool thickness. The tooling system is designed to cure at ambient temperatures and has very low shrinkage so helps to ensure that the plug part is accurately reproduced in the tooling. The tools are cured at 20°C, followed by an initial post cure of 4 hours at 40°C develop full laminate strength, before final postcure to produce a tool that is thermally stable up to 130°C maximum.

**Phenolic Resin System**

Gurit’s history in phenolic resin prepreg systems originated in the Aerospace industry, where phenolic resins provide the optimum level of fire resistance. Due to the molecular make up of phenolic resins it forms a continuous surface of bonded char, which once carbonised forms an insulating barrier to the matrix beneath. This mechanism is what allows it to achieve very low levels of heat release and smoke density and separates it from the other resin systems which are typically reliant on mineral fillers or additives to achieve FST levels, which adds parasitic weight to a composite part. Importantly for the rail industry, Gurit’s PH 840 phenolic prepreg, which was selected for this project is also completely free of halogens.

Although phenolics are often described as ‘brittle’, the formulation of phenolic resins has come a long way, to the point where with a modified phenolic such as Gurit’s PH 840 can achieve fibre dominate strength values close to a conventional epoxy E-glass prepreg. This allows the engineers to develop loading bearing components from these resins.

This resin system is capable of very short curing cycles at 160°C as low as 10 – 15 minutes. However for use with FRP tooling it can also processed at lower temperatures. The cure of these seats was accomplished at a temperature of 120°C, which provides a margin below the tooling systems maximum Tg and help maintains part and tool surface quality over repeat cycles.

**Gurit® G-PET™ FR**

PET cores are part of the industry standard for rail applications, with much lower toxicity levels than PVC foams. Gurit® G-PET™ FR was selected for this project, due to its excellent FST performance and also its high strength to shear loads and point impact. In a sandwich application the core plays an important structural role, by supporting the thin skins against point load impacts, providing resistance against skin wrinkling at highly loaded areas, and naturally supporting the shear loads. Consequently, when selecting the core density, these requirements are carefully balanced against weight, cost and FST performance during the engineering design process to develop and optimised and robust design.

Gurit® G-PET™ FR is also both thermo-formable, and yet can be processed at the elevated temperatures required for the phenolic prepreg. During the manufacturing process, the G-PET™ core is heated to approximately 130°C and then forced onto a male form tool by vacuum. At this temperature the thin section of core is pliable enough to take up the complex curvature of the seat. The foam blanks are then trimmed ready for the main assembly line.

Under vacuum pressure the Gurit® G-PET™ FR is then stable at the 120°C cure temperature and maintains thickness without crushing during the phenolic cure cycle.