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Adhesives for Bus & Rail Floor Bonding:

5 Top Tips for Engineers

Content

Introduction

Demand for rail travel has been rising steadily for more than three decades. Over the past 20 years the number of rail passenger journeys made each year in the majority of European counties has doubled, to more than 3900 billion Pkm, with trains travelling more than half a trillion kilometres every year.[1]

"Rail is among the most energy efficient and lowest-emitting transport modes", according to the Future of Rail report[2] published this year by the International Energy Agency; with increasing focus on sustainability and a trend towards urban living, tomorrow's trains must be designed to be faster to build, easier to maintain and more cost-effective to run.

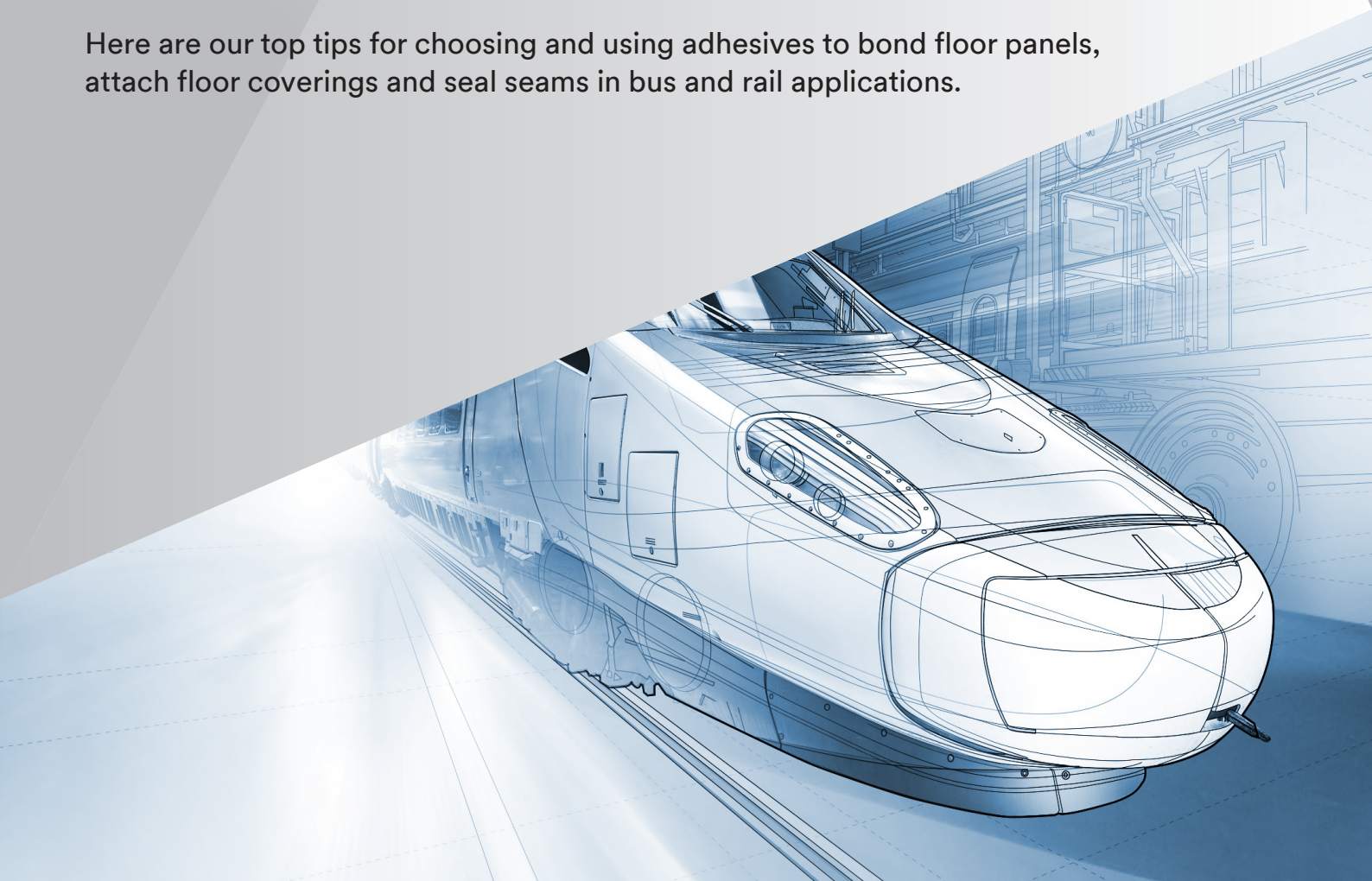
Increased use of lightweight materials and bonding of dissimilar substrates presents new joining challenges to which advanced adhesives technologies are well suited, allowing structural connections to be made between many different materials thus giving Engineers more design freedom. In his writing on *Adhesive Bonding for Railway* Applications, Suzuki states, "the most promising method to join the multi-material structures of trains is adhesion."[3]

High performance tapes and adhesives can provide advantages over traditional attachment methods: they are lightweight, offer chemical, corrosion and moisture resistance, reduce noise and vibration, improve aesthetics and speed up the assembly process.

With the average life of a rail carriage around 40 years and a need to optimise maintenance and overhaul costs, durability is critical. Transport floors can be stressed by constant vibration, twisting and bouncing. Advanced bonding technologies are designed to maintain their effectiveness and elasticity through years of hard use.

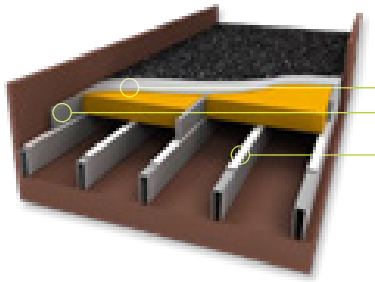
Selecting the right adhesive to meet your design needs can be complex but manufacturers can help by providing expert technical support, relevant test data and a range of bonding solutions: from adhesive transfer tapes, reclosable fasteners and spray adhesives to high-performance foam tapes, adhesives sealants and structural adhesives.

Here are our top tips for choosing and using adhesives to bond floor panels, attach floor coverings and seal seams in bus and rail applications.



Define Your Performance Needs

Applications for adhesives in transportation flooring may include bonding floor panels, coverings and sealing seams.



Floor System Assembly

Floor Cover Bonding
Floor Panel Seam Sealing
Floor Panel Bonding

Depending on the application and overall vehicle performance needs, adhesive selection will need to consider:

- Flexibility
- Shear strength
- Peel strength
- Rate of strength build
- Vibration resistance
- Fatigue characteristics
- Aesthetics
- Temperature range

Defining the most important performance requirements can help narrow down the choice of suitable adhesive solutions. Adhesives can provide very strong bonds – a toughened epoxy can outperform rivets and welds in terms of overlap shear strength. However more elastic adhesives with a lower overlap shear, may offer better flexibility, greater durability and fatigue resistance and allow for expansion when temperatures change.

In vehicles, where floor boards are bonded to the floor framework, adhesive joints may be directly exposed to outdoor conditions – for that kind of open design, durability requirements are higher and aging tests are more demanding.

In rail applications the regulatory aspects of the design are important too, such as the relevant safety class for the bond under DIN 6701, the requirement class for the application under EN 45545-2 and the environmental health and safety characteristics of any products specified. Bus floors installed in vehicles of Category M3, Classes II and III (coaches and school buses) must comply with burning behaviour requirements in accordance with UN/ECE Regulation No. 118.

The importance of aesthetics should not be underestimated for floor bonding applications. When joining thin materials such as floor coverings it may be important to select an adhesive/material combination and bonding process that avoids “read-through”. This is the tendency for distortion during or after assembly to allow the bond line to become visible on the outside of the material.

The validation of a finished floor by the Transit Authority, the comfort experienced by passengers and the ease of maintenance when floor parts are replaced, are key for the vehicle manufacturer to demonstrate quality and win new projects. The adhesives used for the assembly and sealing of the different floor components have to provide perfect finishes and aesthetics to pass Transit Authority requirements, not only at initial delivery but during the entire vehicle life cycle, where the stability of the floor system is affected by fatigue, vibrations, impacts and differential expansion stresses that may generate defects with time. Adhesives with some elasticity may be preferred to very stiff and high shear strength adhesives that, given the size floor systems and the cyclic forces applied on it, can generate cracks between adhesive and substrates due to excessive stiffness of the joint.

Here an adhesive sealant was used to replace rivets for bonding plywood floor panels to a coated metal frame, this offered better reliability, durability and over 20% time saving.

Adhesives can be used to seal the gaps between floor panels. For example, here adhesives from the 3M™ Scotch-Weld™ range are used for bonding (Metal Bonder Acrylic Adhesive DP8407NS and Epoxy Adhesive DP7240) along with 3M™ Hybrid Adhesive Sealant 760.

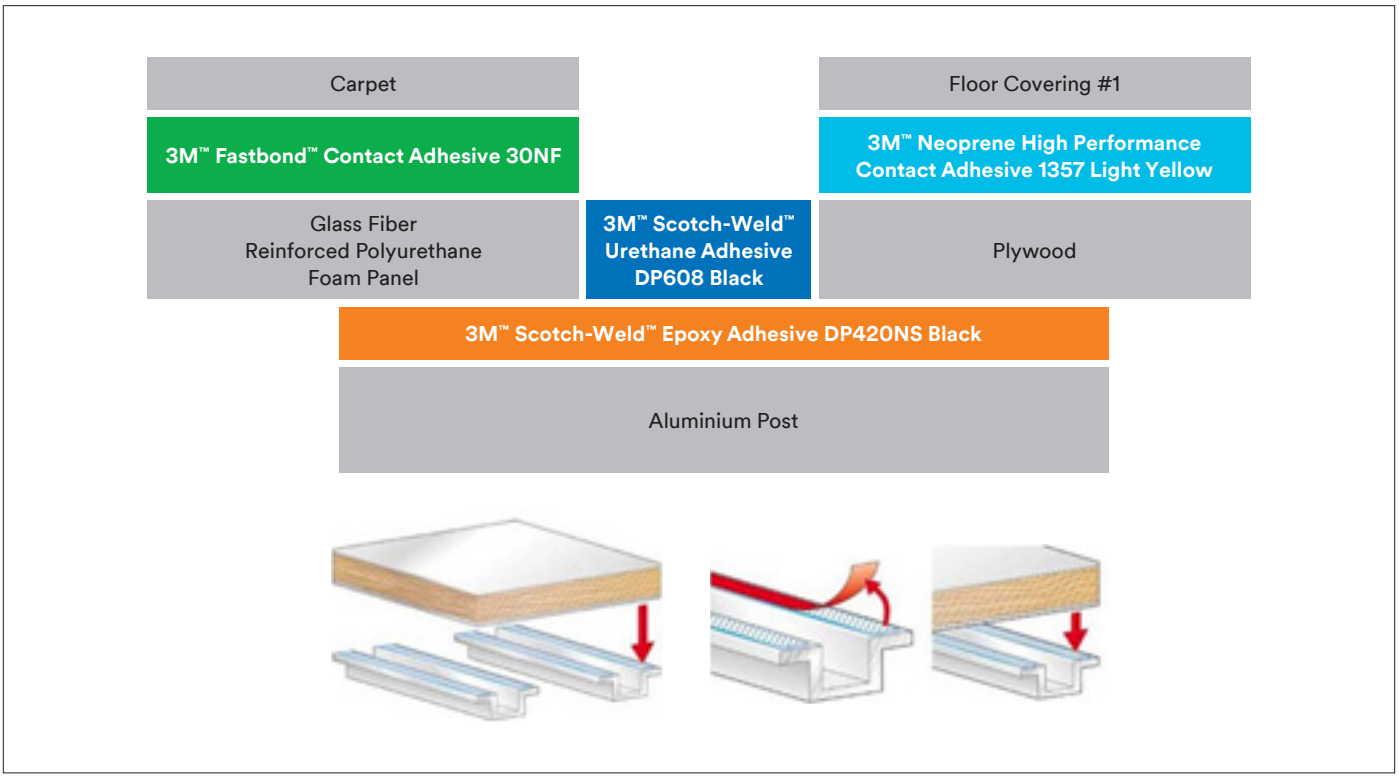
Top Tip #1:

Durability, Flexibility and Aesthetics may be just as Important as Strength

Understand Your Substrates

Floor panels and covers come in a host of substrates, all of which can be held fast by choosing advance bonding technologies. Floor coverings are commonly made from vinyl, polyolefin, rubber or polyamide. Key factors affecting the choice of flooring may be aesthetics, durability, flexibility, weight, slip resistance, moisture absorption, comfort, acoustics, fire/smoke/toxicity characteristics and ease of installation and cleaning. The growing shift to more sustainable solutions may make a proportion of natural/renewable/recycled content desirable. Floor coverings can be bonded on-site or supplied in self-adhesive rolls laminated with a thin, pressure-sensitive adhesive film/tape.

Floor coverings may be applied to compound floors, aluminium floor plates, floor coatings or plywood subfloors. Plywood is still the most commonly used material for bus floors, but there is a high interest of bus manufacturers in lightweight and moisture resistant alternatives, such as all kinds of composite sandwich panels with foam core, aluminium honeycomb panels or even aluminium/cork boards, although they generate more challenges as far as design, production and cost of the floors are concerned. In rail applications, sandwich panels with an aluminium honeycomb core are a common construction, their light weight, stiffness and energy absorption characteristics being ideal for transport applications. Weight reductions of up to 40% compared have been achieved by replacing plywood structures with composite panels requiring fewer supports.



Substrates drive choice of potential adhesive candidates and vary in their ability to be bonded. This reflects differences in surface energy and chemistry of the substrates. When selecting an adhesive, consider the surface condition and texture of each material as well as use, impact and durability.

Adhesion to the substrate is a key criterion; without robust adhesion leading to cohesive failure, one is unable to design to the substrate and adhesive mechanical properties. The design engineer should test the specific product to be bonded as well as verifying the necessary surface preparation requirements prior to making a final adhesive selection. It is important to partner with an adhesive supplier who can provide not only material property data but also assist with screening testing to ensure a robust choice is made.

For large surface lamination of floor coverings, shear and tensile forces, while present, are often negligible due to the large bond area over which to disperse the load. Most large surface laminations involve attaching a flexible surface to a more rigid surface, making peel a key failure mode to consider.

There are several adhesive technologies that can be considered; each adhesive solution provides different benefits in performance, aesthetics and productivity, as well as maintenance advantages. **Table 1** compares different adhesive technologies for floor cover bonding in terms of substrates compatibility and process parameters.

Here lightweight floor panels were bonded to metal frames using 3M™ Scotch-Weld™ Epoxy Adhesive DP125. The adhesive's low viscosity offered excellent self-levelling properties with strong adhesion to GRP.

	1K Silane Modified Polymer (low viscosity)	**2K Polyurethanes / 2K Epoxies**	**Water Based Sprayable**	**Solvent Based Sprayable**	**Acrylic Thin Tapes** (0,05–0,13mm)	**Acrylic Thick Tapes** (>0,6mm)
Main value	100% solids, hand appliable, initial repositioning, low EH&S impact	Gap filling, high strength, self-levelling, initial repositionning	Sprayable, low EH&S impact	Sprayable, high instant adhesion	Self-adhesive, convenient, fast application	Self-adhesive, gap filling, fast application, thermal insulation
Main limitations	Curing time to full strength 1mm/24h*	Isocyanates or Bisphenol EH&S issues	Limited thickness, check substrate compatibility	Limited thickness, shrinkage, solvent issues (EH&S)	Thin bondle, may affect aesthetics	Strong adhesion build-up, end-of-life removability, adhesion to flocked coverings
Processability	Easy, no mixing required	Difficult, mixing required, long curing time	Easy with spraying	Easy, personal protection required	Very easy, may require floor panel smooth finishing	Very easy
Performance	Elastic, no shrinkage, long term durable, moisture resistant	Stiffer, higher resistance and durability	Good average resistance	Good average resistance	Good average resistance	Strong bond, visco-elastic, water-tightness
Aesthetics	Average good aesthetics	Good aesthetics (self-levelling) but may cause seams sealing cracks	Average less aesthetic finish	Average less aesthetic finish	Average less aesthetic finish	Good aesthetics, no cracks visible in flooring due to panel seam seals
Maintenance	Can be removed with mechanical means	Very difficult to remove	Can be removed with mechanical means	Can be removed with mechanical means	Easier to remove	Can be removed with mechanical means

Table 1: Adhesive Technologies for Floor Cover Bonding in Transportationoffered excellent self-levelling properties with strong adhesion to GRP.

* Note that some products are now available for floor cover bonding with a bond thickness ~0.3mm and a walk-on time of just two hours which can be faster than a 2K polyurethane products.

3M has a wide range of industrial tapes and adhesives so whichever technology you choose, you are likely to find something that will provide the right combination of properties for your application. Some examples are provided below.

- **3M Silane Modified Polymer 75039** adhesive combines gap filling properties with easy hand application and fast curing without shrinkage. It bonds to most floor cover materials and floor panels without primer or isocyanates, simplifying processes and providing environmental health and safety benefits.
- **3M 9775WL self-adhesive transfer tape** can be pre-laminated to floor coverings before installation, a convenient solution for a fast and clean application and easier removal for maintenance operations. It is a thin tape that provides a good thermal conductivity for self-heating floors, improving energy efficiency.
- **3M 1000NF sprayable water-based adhesive** is easily applied with spray equipment. In some cases, it can be applied on one substrate only, simplifying the application process and reducing labour costs. The high-solid content, acrylic water-based formula reduces environmental impact.
- For difficult to bond surfaces, like low and medium surface energy plastics (ABS, PA, PE, PP), consider **3M VHB LSE tapes** or **3M DP8005 structural adhesive**. These bonding solutions help Design Engineers to define assemblies with a strong bond, high durability, good aesthetics and reduced need for rivets and screws which can damage plastic structure.
- **3M VHB GPH acrylic foam tapes** have shown excellent plasticizers or additives migration resistance when bonding PVC or EPDM materials, being used in many floor cover bonding, kickplate and gasketing applications.

Top Tip #2:

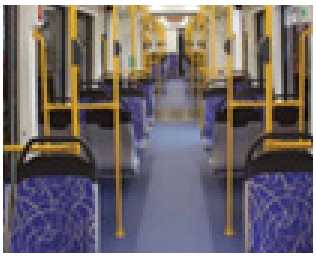
Consider a Hybrid Solution

Assess the Process

With a wide range of options and bonding chemistries available, such as laminating adhesives and sprayable adhesives for applying floor coverings, and high-performance foam tapes, acrylic and epoxy adhesives for bonding floor panels, the selection can be narrowed by asking some key questions about the application process, such as:

- What is the current assembly and bonding process?
- Does the solution need to fit into the current process/equipment?
- Can the process/equipment change to accommodate the solution?
- What are the various steps involved?
- How quickly will the assembly transition through each step?
- How important is speed?
- Is there an opportunity to reduce process steps or components?
- At any time, might the assembly bond need to be repositioned?
- If so, why and when?
- Who will be doing the bonding?
- What environment will the bonding be done in? Temperature, moisture, dirt?
- What are the environmental, regulatory or transportation safety considerations?

For example, this floor panel assembly was bonded with 3M™ VHB™ Tape 4991 which gives instant adhesion and defines a minimum thickness. 3M™ Hybrid Adhesive Sealant 760 was used for gap-filling where needed.



3M™ Adhesive Transfer Tape 9775WL can be pre-laminated onto floor coverings delivered ready to apply with fast and clean application and good finish quality.

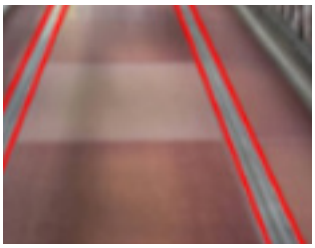
Surface preparation is an important part of the process; contaminants or weakly bound surface layers must be removed prior to bonding—generally using solvent-based degreasers and abrasion to remove oxidation.

Adhesives with fast cure times or tapes which give an immediate bond enable walkability and help to speed up the assembly process and improve productivity.

Uneven surfaces can be accommodated using adhesives with good gap-filling properties. Tapes can provide a consistent bondline, in some cases removing the need for spacers.

Environmental, health and safety aspects are also an important process consideration. It may be desirable to reduce or eliminate particular chemicals in order to comply with legislation or health and safety policies. Tapes are low hazard products which are simple and easy to apply so can offer advantages in this area.

When bonding bus floor coverings an instant bond is often required and floors, especially in city buses, are typically not flat due to presence of wheel arches and different kind of interior platforms. Adhesives that bond on contact, such as sprayable contact adhesives or self-adhesive materials (pressure sensitive adhesives) are commonly used to help accommodate vertical surfaces and complex floor shapes. Bonding tapes allow for single-sided application, can be pre-laminated and offer fast and clean application.



In this case, 3M™ VHB™ Tape 4918 saved 12 hours (compared to a polyurethane adhesive) and the consistent 2mm bondline eliminated the need for spacers.

Testing and Regulation

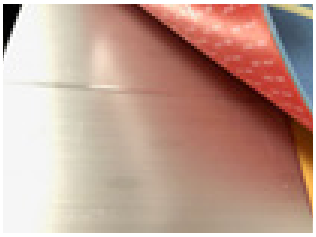
For rail applications, adhesives manufacturers can assist Engineers in the development of bonding descriptions according to DIN 6701 (German national standard covering bonding of rolling stock and vehicle parts) based on relevant test results. Floor panel bonding is typically classified as A2 safety class (average safety requirements; failure may result in accidents involving physical injury of persons or impairment of serviceability) and floor cover bonding A3 (low safety requirements; failure results in loss of comfort). Therefore, personnel responsible for production and maintenance must be qualified to European Adhesives Specialist level. This approach is widely adopted across Europe and the development of European draft standard, prEN 17460, is based on it.

Adhesive bonding in buses has not been yet regulated by any specific, broadly applicable European or industry standard. However, as a special process, it is subject to the internal procedures of manufacturers and must meet certain technical requirements, ensuring adequate strength, durability and aesthetics of the bond. At some bus producers, the requirements, for ageing for example, are similar to those used for rail vehicles and bonding specialists are also qualified European Adhesives Specialists. It is likely within a decade that many bus manufacturers will benefit from certification to DIN 2304, an industry-wide user standard for all types of bonded joints and based on the success of DIN 6701. This will lead to classification of floor panel, and floor covering bonding, in buses as safety classes S2 and S3 respectively, and unify the requirements for adhesive joint verification and bonding process supervision.

DIN 50014 and ISO 9142 are widely used standards for testing floor cover and floor panel assembly's resistance to harsh environmental conditions. The condensed water climate test ("cataplasma"), included in DIN 50014 standard, is one of the most aggressive ageing tests for substrates and adhesive joints, with conditions that simulate extreme outdoor conditions in an alternating cycle with dry heat and cold temperature. Adhesives and substrates must not show significant degradation after these ageings, and corrosion can be an issue when using metal floor panels with adhesives that do not protect the metal from water intrusion. In this way, adhesives that provide water tightness should be preferred to adhesives that only bond one substrate to another without sealing: acrylic foam tapes, epoxy and SMP adhesives with gap filling and sealing properties offer a better water tightness than adhesives in dispersed format (solvent or water) and adhesives with shrinkage after curing like polyurethanes.

Top Tip #3:

Consider Tapes Instant Adhesion and Improved Health & Safety



3M™ VHB™ Tape GPH provides gap-filling, thermal and acoustic insulation properties.

Evaluate the End Use

In the case of rail applications, end-use not only determines the best adhesive selection but also the testing and bonding processes that must be employed.

Some general questions to consider are:

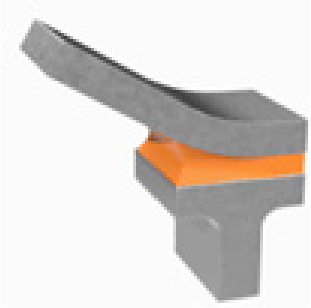
- What is the end use of the flooring panel, and what is the desired life span?
- How important are aesthetics?
- Is a smooth appearance important?
- How long does the floor covering need to last for?
- How often is it likely to be replaced and to what extent?
- What is the cleaning process for the flooring?
- Will the assembly be exposed to harsh environmental conditions, such as?
  - high foot traffic
  - vibration
  - ultraviolet radiation
  - chemicals
  - high humidity
  - extremes of temperature

In safety-critical applications materials must comply with stringent fire, smoke and toxicity (FST) regulations. While these requirements were once seen as a barrier to the adoption of certain materials, manufacturers have made significant progress in the development of a wide range of resins, fibres and coatings, adhesives and tapes all with excellent FST performance. Under EN 45545-2 (railway applications – requirements for fire behaviour of materials and components), flooring constructions including adhesives are classified under material requirements set “R10”. This dictates a specific set of tests and gives performance levels required for use in the various hazard levels (based on the operation and design categories, for example double-decked vehicles). Although the assembly must be tested in its end-use condition, adhesive manufacturers can often provide indicative test results which provide a guide as to how their products will perform.

With a trend towards designs enabling assets to operate for longer, with fewer overhauls and maintenance interventions, the long-term durability of components and assemblies is becoming increasingly critical. Structural adhesives and high-performance tapes can help to improve durability in several ways. For example, unlike mechanical fasteners, rivets or spot welding where mechanical stress is concentrated at specific points, structural adhesives distribute stress uniformly across the bonded area. They can also prevent galvanic corrosion between dissimilar metals and are able to resist high loads, and degrading agents such as fuel and solvent based cleaners.

Top Tip #4:

Combine Fastening with Adhesive Bonding to Counteract Peel



In floor covering bonding applications, delamination due to peel is a common issue. Adhesives and tapes are weakest in one-dimensional stresses concentrated on the leading edge of a bond. Luckily, this is where mechanical fastening performs best. The easiest way to mitigate peel in a surface lamination is by incorporating mechanical fasteners at the edge of the bond. These serve as peel terminators and prevent cracks from propagating through the bulk of the bond. If, for aesthetic reasons or otherwise, mechanical fasteners are not appealing, incorporation of transition strips or mechanical lips to the design can provide a smooth transition from one surface to another and provide the same benefit of peel-terminating rivets.

Consider Total Cost

With a focus on designing for maintenance and recyclability and a typical lifecycle for rail of approximately forty years, it is vitally important to consider the total cost of a design choice.

From an Engineering perspective, in rail vehicle design and manufacture, maintenance or overhaul, there are often small but simple changes in approach, tools or materials that can have a significant impact.

Consider where can improvements and savings can be made in the assembly, bonding and disassembly processes?

- Labour saving
- Time saving
- Reduction of process steps
- Less material
- Few safety control measures
- Optimised workflow
- Lighter weight
- Easier disassembly

Bonding can contribute to direct weight savings by replacing mechanical fasteners or allowing the elimination of additional sealing insulation or soundproofing components. It can allow the use of lighter-gauge materials by eliminating stress concentrations and allowing optimal load distribution across component interfaces.

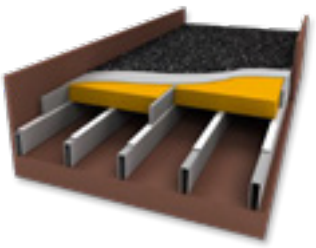
When rail assets do require repair or routine maintenance, the choice of assembly technology can also have a significant impact on the speed and simplicity of these activities and therefore cost. For semi-permanent fixtures, like floor coverings, high-performance tapes can combine safety and durability in use with fast removal when replacement is required.

Tapes and adhesives can also be used for bonding skirting and threshold panels and specialist tape products are available for demarcation and hazard awareness.

Top Tip #5:

Use Tape to Accommodate Small Mismatches between the Panel and Structure

Pressure sensitive tapes can offer quick and easy low skill assembly and potentially low volatile emissions over traditional solvent adhesive liquid solutions. No curing time and instant walk on can be other benefits. Also, no clean up and you use only what you need in a simple to handle product format. These can be pre-applied off site to allow even quicker assembly on the main production line. All this with additional vibration damping properties.



3M™ VHB™ Tape 4991 offers a strong bond with instant adhesion and vibration damping properties.

Summary

To maximise the benefits offered by lightweight and composite materials and overcome the challenges of joining dissimilar materials, Engineers can choose from a wide range of adhesive technologies which can provide advantages over traditional attachment methods including increased corrosion resistance, reduced noise and vibration, improved aesthetics and fast assembly. To make the best choice, Engineers should define the performance needs, understand the substrates, assess the process, evaluate the end use and consider the total cost, whilst all the time being aware of the relevant regulatory requirements.

Here is a reminder of our top five tips for transport flooring applications:

- Durability, Flexibility and Aesthetics may be just as Important as Strength
- Consider a Hybrid Adhesive Sealant for Gap Filling
- Consider Tapes Instant Adhesion and Improved Health & Safety
- Combine Fastening with Adhesive Bonding to Counteract Peel
- Use Tape to Accommodate Small Mismatches between the Panel and Structure

References

[1] https://uic.org/support-activities/statistics/#Rail-transport-in-the-world

[2] International Energy Agency 2019, Future of Rail, accessed 1 Nov 2019, <https://webstore.iea.org/the-future-of-rail>

[3] Suzuki Y. (2018) Adhesive Bonding for Railway Application. In: da Silva L., Öchsner A., Adams R. (eds) *Handbook of Adhesion Technology.* Springer, Cham <https://doi.org/10.1007/978-3-319-55411-2_47>