

The use of sleepers made of FFU synthetic wood in Europe

Since 2004, railway sleepers made of FFU synthetic wood have been in use in Europe on railway bridges with open load-bearing structures made of steel as well as under points and crossings. In September 2008, Munich's University of Technology wrote the final report on a research project into such sleepers, drawing positive conclusions.

The letters "FFU" stand for "fibre-reinforced foamed urethane", the material used in Japan to develop a synthetic wood. Back in 1978, a company called Sekisui was awarded several prizes in Japan for this technological development, which initially went under the name of "Eslon Neo Lumber FFU". FFU synthetic wood is a material that has the same material properties as natural timber and can be handled and processed as easily as it can. The synthetic material has virtually the same specific mass as the natural one, yet a very considerably longer service life than the latter, and its weathering properties are also superior.

In 1980, the Railway Technical Research Institute (RTRI), working in cooperation with the Japanese railways, laid sleepers made of this material on two experimental sections of track in Japan. Following on from a period of five years of practical experimentation, in which all the specified requirements were fulfilled, "Eslon Neo Lumber FFU" has since then been used by the Japanese railways as a standard product on steel structures, under points and crossings and in tunnels in combination with both ballasted and ballastless track. In 1996, the RTRI removed the first synthetic-wood sleepers from the experimental track sections and subjected them to a new series of tests. Extrapolating the results recorded at that time, FFU synthetic wood would be expected to have an in-situ service life of more than fifty years. Sleepers made of FFU synthetic

wood have now also been in use in Europe since 2004.

1 Development and production of FFU sleepers

The technique used for the manufacture of FFU synthetic wood is pultrusion. Oriented glass-fibre strands are drawn through a pulling device, coated in polyurethane and cured at a high temperature, to result in a particularly high-grade, pore-free material.

If so ordered, it is possible to manufacture the synthetic wood ex works as semi-finished products in the shape of railway sleepers and bridge timbers with millimetre precision. Some of the different processes that the manufacturing works is capable of applying to its semi-finished products with such tight specifications are listed in Table 1.

Each of the synthetic-wood sleepers produced in the works to meet a precise special requirement is given a unique marking, to make sure that it is laid at the intended location on the engineering site.

2 Reference applications

If all the sections of railway track on which synthetic sleepers made of "Eslon Neo Lumber FFU" have been laid since 1985 are added together, then the total number of kilometres is more than 925. Some of this has been on light-rail systems and some on really heavy rail systems with axle loads in excess of 30 tonnes. The predominant use of FFU synthetic-wood sleepers in Japan has been on the Shinkansen high-speed network, along with applications on regional, cross-country and metro lines.

The first project using FFU synthetic wood in Europe was implemented in 2004 (Fig. 1 and 2). It was part of the general overhaul of the Zollamt bridge in Vienna, an open engineering feature with its load-bearing structure made of steel, which had been designed by Otto Wagner and built originally between

1896 and 1898. The overhaul of the bridge included the replacement of its corrosion protection and the entire track superstructure. The bridge is used by the U4 metro to cross the river Wien. The specifications laid down for the project are listed in Table 2.

The bridge was closed to all traffic for a period of ten days and during that time the superstructure, which had suffered very considerable damage due to the elements, was replaced, and new anti-corrosion measures were applied to the load-bearing structure underneath it. After that, the bridge timbers made of FFU synthetic wood were trimmed and laid in place. The rails were correctly positioned and welded together. Finally, the decking elements were laid and, in order to create an interesting experimental situation, it was decided to use FFU synthetic wood for just half of them. The metro operator, Wien-

Doubling the amount of cant
Drilling screw holes
Milling out the space for the chord reinforcement
Milling out the space for the longitudinal beam
Surface sanding
Milling out the space for the rivet heads

Table 1: Forms of preparation available in the manufacturing works

Compliance with a track closure of no longer than ten days
Minimisation of the duration of the substitute transport service
Minimisation of the negative effects on passengers' comfort and convenience
Obtaining maximum track availability for the future
Best available overall economic solution on the basis of a life-cycle-cost analysis

Table 2: Conditions determining the decision regarding the renovation of the Zollamt bridge



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er Linien, has announced new maintenance intervals for the future (Table 3).

If this maintenance schedule works out in practice, at least another fifty years are going to elapse before passengers are again forced to change to a substitute mode of transport during a metro closure.

Other Projects followed. In 2004, Wiener Linien laid very thin sleepers (only 100 mm high) made of FFU synthetic wood on the Floridsdorf bridge across the river Danube (Fig. 3).

Yet another project launched at about the same time involved replacing the natural wooden parts with FFU synthetic-wood ones on the U4's bridge over the river Wien in the Hütteldorf suburb of Vienna. The railway track describes a curve as it crosses this bridge, and so a company of surveyors was called in to measure each of the old wooden parts with millimetre precision. This data was used to draw up plans for the replacement parts, each of which was given a unique number. In the manufacturing works, the bridge timbers were produced with precision, including the correct amount of cant for each individual position, numbered and finally delivered to the principal.

In 2008, Wiener Linien started a long-term programme for replacing the existing sleepers made of other synthetic materials already in use on its network with new ones made of FFU synthetic wood.

It was in 2005 that the Austrian Federal Railways (ÖBB) first used FFU synthetic wood on the Hackingerstrasse railway bridge, which crosses over a road in Vienna. This bridge is located in the approach to a home signal on a curve with a high cant, and large numbers of freight trains pass over it every day. The ÖBB opted to use FFU synthetic wood, given that the bridge had had a very costly maintenance record. The sleeper screws had needed retightening several times a month. It had also been necessary to replace the former natural bridge timbers repeatedly at intervals of only a few months. The condition of the FFU synthetic-wood sleepers on the bridge has remained as good as new since they were laid in 2005. The sleeper screws have remained reliably firm at all times.

The positive experience with FFU synthetic wood led to the decision to use it for the sleepers on the Karwendel bridge over the river Inn in Innsbruck, when this underwent renovation in 2007 (Fig. 4). The general overhaul of the bridge included improvements to its steel structure, the replacement of the anti-corrosion measures and the durable improvement of the superstructure through the renewal of the bridge timbers.

In the course of 2009, the ÖBB are replacing the bridge timbers on the Ostbahn bridge over the river Danube in Vienna with

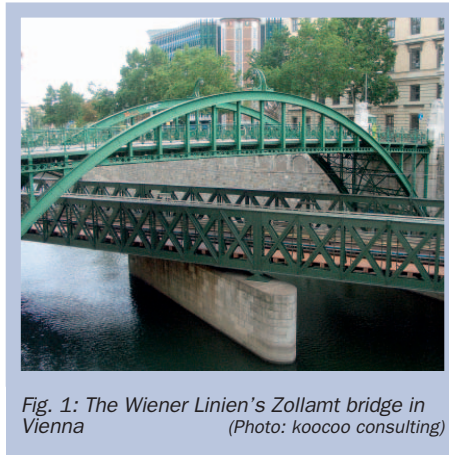


Fig. 1: The Wiener Linien's Zollamt bridge in Vienna (Photo: koocoo consulting)

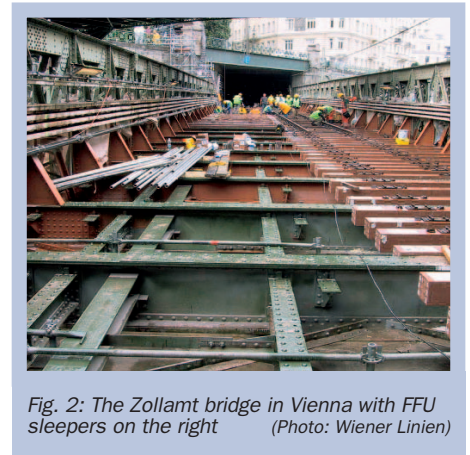


Fig. 2: The Zollamt bridge in Vienna with FFU sleepers on the right (Photo: Wiener Linien)

FFU synthetic-wood ones. Once again, each individual bridge timber is to be measured precisely by a surveyor, and the manufacturer is to produce the new FFU synthetic-wood replacements with millimetre accuracy, including the necessary amount of cant, and to deliver them with the correct final geometry and dimensions.

At the time of writing, the ÖBB are preparing to decide on whether or not to lay FFU synthetic-wood sleepers under a double slip in one of the biggest marshalling yards in Europe, not far from Vienna.

In May 2009, the ÖBB's research and development department is to lay FFU synthetic-wood sleepers with a low-noise coating for the first time in Europe in Hainburg just outside of Vienna in the context of an experimental programme to reduce railway noise.

Turning to Germany next, there Voestalpine BWG laid the first points with a length of approximately 74 metres on FFU synthetic wood in June 2008. The lengths of the point sleepers range from 2.20 to 4.50 metres. BWG used a type of milling cutter to make the necessary holes. It is reported that the geometric stability and evenness of the FFU material was found to be very favourable for preparing the sleepers economically in this way in the factory. This set of points has now been laid in Chempark, Leverkusen (Fig. 5).

3 Research report by the Munich University of Technology [1]

The initial discussions with the objective of creating the preconditions for FFU synthetic-wood sleepers to be authorised by the



Fig. 3: The Floridsdorf bridge in Vienna (Photo: koocoo consulting)

EBA (German Federal Railway Authority) for use on the track belonging to infrastructure managers in Germany (i.e. "DB Netze") took place in January 2008. The tests to be carried out were defined jointly with the transport infrastructure engineering department at Munich University of Technology and the test laboratory linked to it. These tests are listed in Table 4. Komat (an Austrian company) was the principal in this transaction. Komat, together with Sekisui Chemical Co., Japan, was also the organisation that applied to the EBA for an approval for FFU synthetic-wood sleepers.

Sekisui provided twenty FFU synthetic-wood sleepers for the tests with the dimensions of classical natural wooden ones (26 x 16 x 260 cm / width x height x length). It attached Vossloh KS rail fasteners to six of these. The sleeper screws were fastened with a torque of 220 Nm. The following sections present the results of each of the individual tests and examinations.

Rail replacement	Longer than 30 years
Corrosion protection	Longer than 30 years
Bridge timbers in FFU synthetic wood	Longer than 50 years
Steel structures	Longer than 50 years

Table 3: Future overhaul intervals for the Zollamt bridge



Fig. 4: The ÖBB's Karwendel bridge in Innsbruck (Photo: koocoo consulting)



Fig. 5: Point laid in Bayer's Chempark in Leverkusen (Photo: Sekisui)

3.1 Fatigue test

The fatigue test was carried out using the "scissors-lever vibrator" at Munich University of Technology (Fig. 6). The length of rail used for this test had had 15 mm of material removed from the top of it by milling in accordance with DIN EN 13481-3. The dynamic stiffness of the rail pad corresponded to a spring coefficient of greater than 200 kN/mm. The top load in the test was 140 kN, the bottom load 10 kN, and the load-application frequency was 3 Hz. The test load thus matched that in the experimental fatigue load applied to a sleeper laid in a track subjected to wheel-set loads

of 225 kN. Table 5 shows the deflection of the rail relative to the sleeper after three million load cycles at ambient temperature. These are values which experience has shown to be within the admissible range.

Another test phase involved an additional 1.28 million load cycles at the higher temperature of 48 °C. The values measured were of the same order of magnitude as those at ambient temperature. It can be concluded from this that the system's mechanical behaviour is not generally affected by higher temperatures.

3.2 Tensile force in the sleeper screws

For this particular test, recesses are milled into two opposite sides of the shafts of two sleeper screws and strain gauges are glued into these. The screws are calibrated in a centred tensile test, in which it is possible to assign the elongations registered to the corresponding tensile forces. The tensile force in the sleeper screws diminishes as a function of tightening torque and time. This is illustrated in Table 6.

3.3 Screw extraction test

For the extraction test, a central tensile force is applied to the sleeper screws, and the values are recorded using an inserted pressure cell. The tests are carried out on all eight screws in a single synthetic-wood sleeper. The load is increased continuously until the screw is pulled out. The extraction force needed for this was found to be 61 kN, which is very considerably higher than that needed for natural wooden sleepers, for which Munich University of Technology had measured a value of only 35 kN in the same test in 1997.

3.4 Impact test

The purpose of an impact test is to establish how sleepers would behave if subjected to impact loads as the result of the derailment of railway vehicles. This is done in accordance with the technical supply conditions laid down by Deutsche Bahn for "reinforced concrete sleepers – basic principles for dimensioning, design and approvals". This document states that each sleeper tested must undergo two impact tests (I and II). In this, a body with a mass of 500 kg and a cutting edge shaped like a wheel flange is dropped from a height of 75 cm twice for each test and lands on the edge of a sleeper inclined at 30°. For the first of these tests, the point of impact is 25 cm away from the centreline of one of the rails and parallel to the axis of the track. For the second test, the point of impact is 15 cm away from the end of the sleeper, in other words on the outside of the rail.

The impact test was carried out on three sleepers without screw holes in them. The damage caused in the test was limited in the first impact in a narrow zone (90 mm) at the point at which the impact load was applied. The fibres were severed to a depth of 25 mm. The surface deformation at the point of impact showed no more than the shape of the flange (Fig. 7). The behaviour of sleepers made of synthetic wood was thus comparable with those made of natural timber. In the case of the second impact, the fibres were loosened as far as the sleeper's end face, and a wedge-shaped end piece was separated from the sleeper. That is not critical for the sleeper's load-bearing capacity in this area, near its end. It scarcely needs mentioning that the screws

Behaviour of the sleeper under the effect of vertical and horizontal loads in the scissors-lever vibration test. Supported in ballast	By analogy with DIN EN 13481-3: Load requirement for rail fastening systems; fastening systems for wood sleepers
Tightening test for establishing the tensile force in sleeper screws dependent on torque	
Extraction test on sleeper screws	In accordance with DIN EN 13841-2: Performance requirements for fastening systems; fastening systems for concrete sleepers
Impact test for simulating the effects of derailments	In accordance with Deutsche Bahn's delivery terms and conditions
Electrical resistance	In accordance with DIN EN 13146-5: Test methods for fastening systems; determination of electrical resistance
Static and dynamic test of the synthetic-wood sleeper	By analogy with DIN EN 13230-2: Track; concrete sleepers and bearers; prestressed monoblock sleepers
Fatigue test in the middle of the sleeper	In accordance with DIN EN 13230-4: Track, concrete sleepers and bearers; prestressed bearers for switches and crossings
Fatigue test under the rail support	In accordance with DIN EN 13230-2
Static compressive test	
Static deflection of the synthetic wood sleeper at ambient temperature and -10 °C	

Table 4: The tests carried out by Munich University of Technology on FFU synthetic-wood sleepers

holding the ribbed base plate into place are not negatively affected by such loads. The FFU synthetic-wood sleepers did not show any signs of warping or twisting as a result of the impact loads. This also means that the track gauge remained constant.

3.5 Electrical resistance

The electrical resistance of the synthetic-wood sleepers was measured between two 50 cm-long sections of UIC-60 rail, fastened to them. A layer of insulation was inserted between the sleeper and the ground and rain was simulated by sprinkling water on it from four nozzles for two minutes. Electricity was applied to the two lengths of rail at 30 V/50 Hz. The tests were performed on subsequent days, giving the synthetic-wood body sufficient time to dry off between the individual measurements. The standard underlying the test, DIN EN 13146-5, requires a minimum resistance of $R_{33} \geq 5 \text{ k}\Omega$ as the mean of three measurements. The tests produced a value of $R_{33} = 71.9 \text{ k}\Omega$ for the electrical resistance of FFU synthetic wood, so it was shown to satisfy the permissible minimum value with a very big safety margin.

3.6 Static test in the middle of the sleeper

In order to examine the behaviour of an FFU synthetic-wood sleeper under conditions of bending stress, a static test was applied to the middle of the sleeper basically along the lines of DIN EN 13230-2, with a distance between supports corresponding to the mean distance between the centrelines of the rails, namely 1500 mm (Fig. 8). The width of the load plate was 100 mm. The test force applied initially was 20 kN and this was then increased in increments of 5 kN, during which the amount of deflection in the synthetic-wood sleeper was recorded on four dial gauges. Up as far as a load of 240 kN (which corresponds to a bending tensile stress of 74 N/mm^2 on the underside of the sleeper) no crack was detected in the bent zone. On the basis of the measured deflection, the modulus of elasticity of the synthetic-wood sleeper was calculated to be around 7000 N/mm^2 . An analogous test was performed on a wooden sleeper made of beech with the same dimensions. For the same test setup, that sleeper failed under a load of 80 kN in the zone affected by the bending tensile stress. The measurements are presented in Fig. 9.

3.7 Fatigue test in the middle of the sleeper

How the synthetic-wood sleeper behaves when subjected to repeated loads was investigated in the form of a fatigue test (using the same width between supports of 1500 mm as for the static test). The load was applied through an articulated support with a width of 100 mm and was increased from its original value up to 100 kN. After



Fig. 6: Scissors-lever vibration test at Munich University of Technology
(Photo: Munich University of Technology)



Fig. 7: Result of Impact test I
(Photo: Munich University of Technology)

Elastic rail-head deflection		Permanent rail-head deflection	
Right support	Left support	Right support	Left support
2.12 mm	1.71 mm	0.42 mm	0.29 mm

Table 5: Fatigue testing of FFU synthetic wood – rail-head deflections

Torque	Time	Tensile force
200 Nm	t = 0	21 kN
200 Nm	t = 40 min.	18 kN
250 Nm	t = 0	25 kN
250 Nm	t = 40 min.	22 kN
250 Nm	t = 3 days	20 kN

Table 6: Tensile forces in sleeper screws

that, the fatigue test was performed with the following load parameters: top load = 86 kN, bottom load = 21.5 kN and frequency = 2 Hz. The maximum bending moment produced was 30 kNm, which corresponds to the test value laid down for sleepers in DBS 918 143 (DBS=Deutsche Bahn Standard) – in other words, these were extremely critical test conditions. No damage was detected on the synthetic-wood sleeper in the course of the whole fatigue test of 2.5 million load cycles. The elastic deflection after this time was only 0.4 mm more than it had been at the start of the test. The deformation followed a more or less constant course throughout the whole duration of the test, and no signs of fatigue occurred. Nor was there any perceptible difference in the measured elongation after 2.5 million load cycles. Finally, the synthetic-wood sleeper was subjected to a load of 175 kN, corresponding to a bending tensile stress of 56 N/mm^2 , but no cracks occurred.

3.8 Fatigue test under the rail pads

The compressive fatigue test under the rail pads follows the basic principles of DIN EN 13230-2 (which actually deals with reinforced concrete sleepers), with a spacing of 600 mm between pads. The load is applied through the fastenings for the ribbed

baseplates with the complete rail fastening in place. A force of 150 kN acting through the rail pad was chosen for the fatigue test. This corresponds to unfavourable conditions in real life, such as a poorly positioned track, uneven distribution of loads through the rails, stiff rail supports and a high dynamic allowance for a static wheel-set force of 250 kN. No damage to the synthetic-wood sleepers was observed during the fatigue test with two million load cycles. The elastic deflection at the end of this period was only 0.2 mm greater than beforehand.

3.9 Static compressive test

For the purpose of investigating the behaviour of the synthetic wood when a sleeper is subjected to a vertical load, it was laid on a flat surface and a vertical force, representing the force acting through a rail pad, was applied through the rail and a fully assembled rail fastening, including a ribbed baseplate. No plastic deformation was detected up to a load of 150 kN, while the maximum plastic deformation of 0.8 mm was measured for a load of 300 kN.

3.10 Static deflection of the sleeper at different temperatures

These tests were carried out at ambient



Fig. 8: Static test in the middle of a sleeper
(Photo: koocoo consulting)

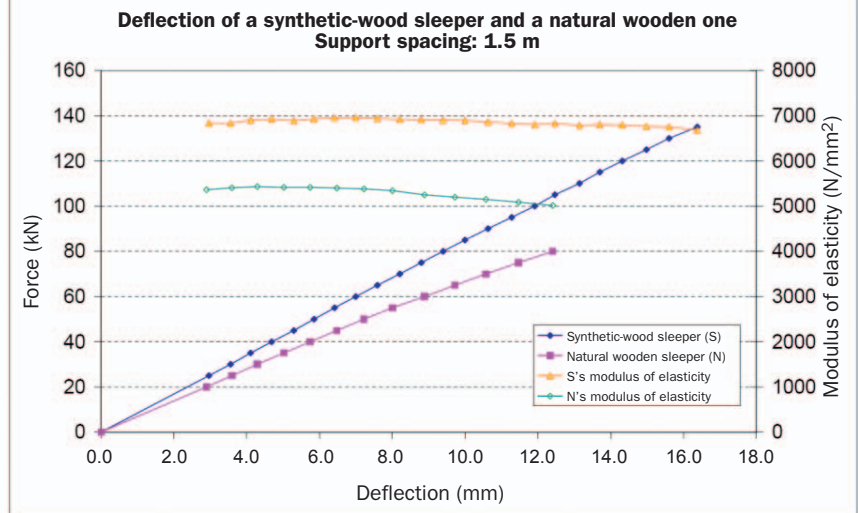


Fig. 9: Deflection of a synthetic-wood sleeper and a natural wooden one
(Photo: Munich University of Technology)

temperature and at -10 °C, with a spacing of 1.0 metres between supports and a test force going up to a maximum of 200 kN. In the case of the low-temperature tests, the synthetic-wood sleepers were kept at -20 °C for two days previously in a climate-controlled storeroom. The results of these tests confirmed that the deformation of FFU synthetic-wood sleepers subjected to bend-

ing-moment stress is only marginally temperature-dependent. No embrittlement occurred at low temperatures. There was no significant change in deformation between the first and third load application. From this, it may be concluded that the fibres do not even fracture at low temperatures when a bending stress with this intensity is applied.

4 Concluding summary

Esilon Neo-Lumber FFU synthetic wood for use in railway tracks was developed in 1978 and since 1985 has been used for more than 925 km of track in Japan, the People's Republic of China, Taiwan and Europe. It has been in use in Europe since 2004 on open load-bearing structures in steel and under railway points and crossings. In September 2008, Munich University of Technology presented the final report on a research activity into the properties of FFU synthetic-wood sleepers, and its findings can certainly be summarised as positive.

In terms of mechanical properties and inherent mass, synthetic-wood sleepers are comparable with classical ones in natural timber. Their bending stiffness is higher than that of classical sleepers made of beech, while their bending tensile strength has even been found to be very much higher. Synthetic-wood sleepers are thus capable of undergoing very much greater elastic deformation without the formation of cracks. In the fatigue tests carried out by Munich University of Technology regarding plastic deformation caused by high rail-pad forces, sleeper-screw extraction forces and impact-test behaviour, the FFU synthetic-wood sleepers performed brilliantly. Moreover, they have a markedly high electrical resistance between two rails fastened in the normal positions and show no signs of embrittlement caused by low temperatures. The EBA (German Federal Railway Authority) granted its approval for FFU synthetic wood in April 2009.

Reference

[1] Research Report No. 2466 of 19 September 2008 by Munich University of Technology, transport infrastructure engineering department and test laboratory, Univ. Prof. Dr.-Ing. Stephan Freudenstein

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