FFU SYNTHETIC SLEEPER – PROJECTS IN EUROPE

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KEYWORDS: Synthetic sleeper, long life time, much better technical figures and weather resistance then regular sleepers from wood, used on bridges and switches, installed in any kind of track, more than 1,300 km track are running on FFU since 1985

ABSTRACT
In the 1970tes JR Japanese Railways after many yours of maintenance observation realized that around 70% of installed sleepers from wood have a very short life time, this because the existing weather influences where leading to moldering and rotting of wood. JR decided to develop alternative material so that life time of sleepers can be increased and track behavior advantages of wooden sleepers can be reached.

The letters "FFU" stand for "fibre-reinforced foamed urethane", the material used in Japan to develop a synthetic sleeper. 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 sleeper is from 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 proper ties 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, 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 ballast less track. In 1996, the RTRI removed the first synthetic sleepers from the experimental track sections and subjected them to a new series of tests. Extrapolating the results recorded at that time, FFU would be expected to have an in-situ service life of more than fifty years.

Since 2004, railway sleepers made of FFU 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. 2011 DB AG – German Railways installed first time FFU on a 60 m long bridge in Vilsbiburg. 2012 DB AG used FFU for two 60.000 t/day switches in Wurzburg. [2]

In 2011, 30 years after the first field test, RTRI again did laboratory test with sleepers removed from first field test. This 30 years old and under regular train operation used sleepers showed that the technical figures have been decreased a little. The conclusion of this test was that RTRI wrote a letter to JR – Japanese Railway operator - that they can still use these FFU sleepers for the next 20 years.

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 millimeter 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 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.

Table 1: Forms of preparation available in the manufacturing works

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

REFERENCE APPLICATIONS

If all the sections of railway track on which FFU synthetic sleepers have been laid since 1985 are added together, then the total number of kilometers is more than 1.300.

Some of this has been on light-rail systems and some on really heavy rail systems with axle loads in excess of 30 tones. 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. 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 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, Wiener Linien, has announced new maintenance intervals for the future (Table 2).

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. Since them Wiener Linien already installed all of their open steel bridges. They also will install it on 78 switches in the area of their rolling stock garage, starting 2013. Wiener Linien also will change all polyurethane sleepers from VAE on their existing tracks within the next 15 years with FFU.

Figure 1: FFU-Floridsdorferbrücke-Wiener Linien-Vienna, Austria

Figure 2: FFU-Vilsbiburg-DB AG-Germany

It was in 2005 that the Austrian Federal Railways (ÖBB) first used FFU synthetic sleeper 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 sleeper, 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 sleepers on the bridge in 2011 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 led to the decision to use it for the sleepers on the Karwendel bridge over the river Inn in Innsbruck, in Ostbahn bridge over the river Danube in Vienna and one more than 7 other bridge projects of their network. In 2010 ÖBB installed first double slab with synthetic sleepers in the area of the new main train station in Vienna.

Turning to Germany next, there Voestalpine BWG laid the first points with a length of approximately 74 meters on FFU synthetic sleeper in June 2008. The lengths of the point sleepers range from 2.20 to 4.50 meters. 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 favorable for preparing the sleepers economically in this way in the factory. This set of points has now been laid in Chempark Leverkusen. Since them German federal Railways DB, Hamburger Hochbahn, Rheinbahn, MVV from Munich uses FFU on bridges, switches or as 10 or 12 cm flat sleepers on the regular track.

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 2: Future overhaul intervals for the Zollamt bridge

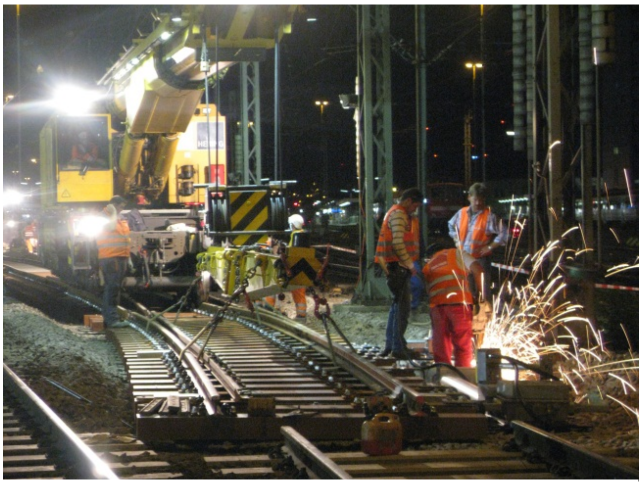


Figure 3: FFU-Würzburg - switches-DB AG-Germany

Figure 4: FFU-Vosdijk in Arnhem – 3 bridges
ProRail, Netherland

Figure 5: FFU-double slab –
ÖBB, Vienna, Austria

The German federal Railways DB AG installed FFU in 2011 on a approx. 60 m long steel bridge, also as flat sleepers on two 10 m long bridges in ballast track, in 2012 on another bridge with approx 20 m length and on two switches in Wurzburg with a daily pass over axel tonnage from 60,000 t. DB also considers to install a long bridge in Cologne over the river Main and another one close to Duisburg in 2013/14.

ProRail from Netherland installed three bridges with FFU in 2012.

BLS, SOB, RHB railway companies from Switzerland will install first projects in 2013 with FFU and already consider using FFU on projects coming in 2014 and 2017.

NetworkRail considers installing FFU also as longitudinal sleeper in 2013. London metro is ready to do the first trial with FFU in the near future.

Figure 6: FFU-sawing on site

Figure 7: FFU-drilling on site

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 authorized by the 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.

Sekisui provided twenty FFU synthetic 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.

Behavior 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; pre stressed mono block sleepers
Fatigue test in the middle of the sleeper In accordance with DIN EN 13230-4: Track, concrete sleepers and bearers; pre stressed 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 3: The tests carried out by Munich University of Technology on FFU synthetic-wood sleepers

<u>Fatigue test</u>

The fatigue test was carried out using the "scissors-lever vibrator" at Munich University of Technology.

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 behavior is not generally affected by higher temperatures.

Table 4: Fatigue testing of FFU synthetic wood – rail-head deflections

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

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 centered 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 5.

Table 5: Tensile forces in sleeper screws

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

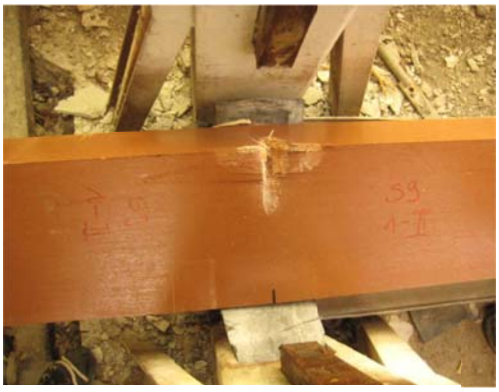
Screw extraction test

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 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.

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 center line 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 fibers 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. The behavior of sleepers made of synthetic wood was thus comparable with those made of natural timber.

In the case of the second impact, the fibers 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 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.

Electrical resistance

The electrical resistance of the synthetic 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 R33 ≥ 5 kΩ as the mean of three measurements. The tests produced a value of R33 = 71.9 kΩ for the electrical resistance of FFU, so it was shown to satisfy the permissible minimum value with a very big safety margin.

Static test in the middle of the sleeper

In order to examine the behavior of an FFU synthetic 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 centerlines of the rails, namely 1,500mm. 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.

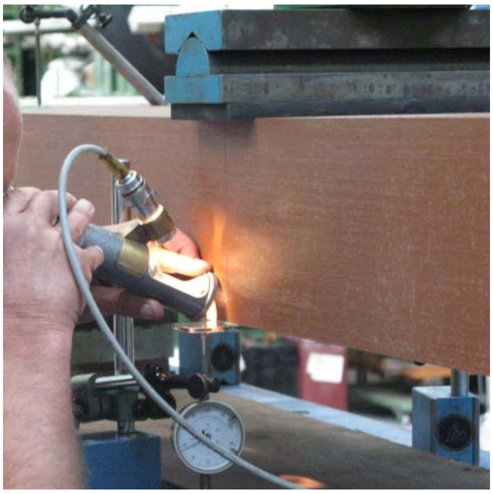


Figure 9: FFU – static test in the middle of the sleeper - TU Munich

Up as far as a load of 240 kN (which corresponds to a bending tensile stress of 74 N/mm2 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 7,000N/mm2.

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.

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 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 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/mm2, but no cracks occurred.

<u>Fatigue test under the rail pads</u>
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 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.

<u>Static compressive test</u>
For the purpose of investigating the behavior of the synthetic sleeper 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 base plate.

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.

<u>Static deflection of the sleeper at different temperatures</u>
These tests were carried out at ambient temperature and at -10 °C, with a spacing of 1.0 meters between supports and a test force going up to a maximum of 200 kN.

In the case of the low-temperature tests, the synthetic 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 bending-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 fibers do not even fracture at low temperatures when a bending stress with this intensity is applied.

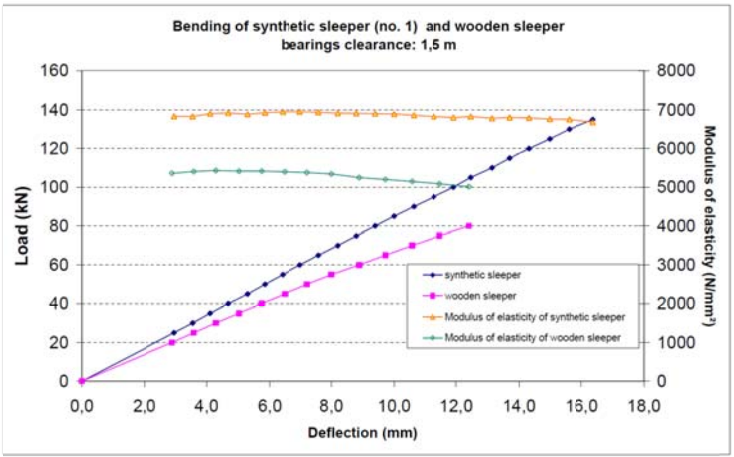


Fig 10: Load – Deflection chart from FFU and wood – TU Munich

CONCLUSION

In the 1970tes JR Japanese Railways after many yours of maintenance observation realized that around 70% of installed sleepers from wood have a very short life time, this because the existing weather influences where leading to moldering and rotting of wood. JR decided to develop alternative material so that life time of sleepers can be increased and track behavior advantages of wooden sleepers can be reached.

FFU synthetic sleeper for the use in railway tracks was developed in 1978 and since 1985 has been used for more than 1.300 km of track in Japan, the People’s Republic of China, Taiwan, USA 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 sleepers, and its findings can certainly be summarized as positive.

In terms of mechanical properties and inherent mass, synthetic 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 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 behavior, the FFU synthetic 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. German federal railway DB installed since 2011 bridges and switches with FFU sleepers.

In 2011, 30 years after the first field test, RTRI again did laboratory test with sleepers removed from first field test. This 30 years old and under regular train operation used sleepers showed that the technical figures have been decreased a little. The conclusion of this test was that RTRI wrote a letter to JR – Japanese Railway operator - that they can still use these FFU sleepers for the next 20 years.

REFERENCES

[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

[2] RTR 2/2009 special report, Günther Koller, The use of sleepers made of FFU synthetic wood in Europe