ЗАЛІЗНИЧНА КОЛІЯ ТА АВТОМОБІЛЬНІ ДОРОГИ

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LABORATORY TEST RESULTS OF GLUED INSULATED RAIL JOINTS ASSEMBLED WITH TRADITIONAL STEEL AND FIBRE-GLASS REINFORCED RESIN-BONDED FISHPLATES

Purpose. The authors' aim is to evaluate more precisely the deterioration process of glued insulated rail joints with polimer-composite and steel fishplates regarding to own laboratory tests. **Methodology.** The laboratory tests were executed by three-point static and three-point dynamic (fatigue) bending tests' measurement results related to glued insulated rail joints with fibre-glass reinforced polymer-composite fishplates (brand: APATECH). During the research the static three-point bending tests were performed on rail joints assembled with three different rail profiles (MÁV48, 54E1 (UIC54) and 60E1 (UIC60)) with three specimens, measured on 13 different support bay values before fatigue test, as well as after 3.5 million loading cycles (the degradations process was checked after every 0.5 million cycles) on polymer-composite and steel fishplated rail joints. **Findings.** The investigation of fiber-glass reinforced and steel fishplated rail joints (three-point static and dynamic bending laboratory tests) are in progress. Considering to them, the mechanical deterioration processes were able to be determined by measurements of deflection values compared to original ones (i.e. before fatigue tests). The differences can be pointed out by analysis of measurement results related to both types of glued insulated rail joints (steel and polymer-composite fishplated ones). **Originality.** The goal of this research is to investigate the application of this new type of glued insulated rail joint and to determine the ultimate lifetime of the investigated rail joints, e.g. how much time they can be safely held in the railway track without damage. In the international literature no one has investigated this field of glued insulated rail joints. **Practical value.** The fibre glass reinforced resin-bonded fishplated glued insulated rail joints and 'control' steel fishplated glued insulated rail joints were built into railway line (between Kelenföld and Hegyeshalom state border) in Hungary at three different locations. In this article the investigation of deterioration process of glued-insulated rail joints and steel fishplated glued insulated rail joints are demonstrated only by laboratory bending tests.

Keywords: laboratory tests; fibre glass; fishplate; railway joint; degradation

Purpose

In this paper the authors summarize the laboratory three-point bending tests results related to glued insulated rail joints with special fibre-glass resin-bonded (Russian branded, exact type: APATECH) reinforced plastic fishplates, as well as traditional steel fishplates. Regarding to fisplated glued insulated rail joints the most problems are the false railway control signs due to rail ends failures which resulting the railway capacity restriction. Other problems are for example the implementation of glue material, endposts, rail ends and wear of rail profile inner corner and plastic deformation.

In the international literature the researchers have been dealt with the following subtopics related to insulated or glued insulated rail joints:

– regulations related to design, mechanical dimensioning and formation [15, 26],

– specification of common failures and failure types of rail joints and identifying of the reason of failure [9, 10, 21, 23, 24, 25, 29, 36, 38, 39, 40, 45, 50, 54, 65, 69],

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– enhancement and improvement of rail joints (mechanical joints, insulated joints, as well as glued insulated joints) and components of these rail joints [2, 12, 19, 21, 22, 23, 25, 27, 29, 31, 36, 39, 45, 53, 54, 58, 69],

– evaluation of the significance of various materials of rail endpost on bearing capacity and stiffness of rail joints [2, 16, 21, 22, 23, 25],

– analysis of rail joints in structural and electrical ways [2, 8, 9, 10, 11, 12, 13, 14, 16, 19, 21, 22, 23, 24, 25, 27, 28, 29, 31, 32, 33, 36, 37, 38, 45, 50, 52, 53, 54, 55, 56, 57, 58, 65, 68, 69],

– investigation of elastic and plastic deformation (mainly vertical deflection) behavior of rail joints, as well as the stress-strain distribution in the rail head and fishplates; analysis of wheel-rail contact related to stress-strain distribution and wear process [2, 8, 9, 10, 12, 13, 16, 18, 19, 23, 24, 27, 29, 32, 33, 36, 37, 45, 50, 53, 54, 55, 56, 57, 58, 68, 69],

– examination of the effect of the arc longitudinal form at railhead edges on the evolved stress values in the rail head [12, 57],

– analysis of support characteristics of rail joints, railway tracks and also ballast settlements [1, 34, 35, 36, 45, 64],

– examination of bonding material (between fishplates and rail webs) quality suitability [51, 52, 65, 66],

– investigation of the amount of used bonding material between due to assembly procedure, as well as the influence of the glue surface markings on bearing capacity of the whole rail joints [51, 52, 65, 66],

– analysis of glue material de-bonding symptom [52, 53, 65],

– investigation of the influence of the usage of square and inclined rail joints on the structural behavior of the rail joints [8, 11, 12, 13, 18, 36, 37, 58, 65],

– examination of the effect of the thickness of the endpost element [19, 21, 22, 25, 57, 58],

– analysis of lipping (and/or ratchetting) at rail ends next to endpost element [24, 25, 27],

– analysis of electric arc burning at insulated rail joints in high-speed railway stations [17],

– examination of dynamic effect due to under sleeper pads [34],

– development of special methodologies and techniques for localizing and identification of faults (electrical and/or structural) in rail joints [2, 7, 13, 25, 40, 49, 55, 56, 59, 65],

– examination of dynamic effects due to rail joint failures and or defects [9, 10, 11, 23, 31, 32, 33, 40, 50, 51, 55, 60, 61, 64, 68, 69],

– taking into account of dynamic effects of railway vehicles on railway tracks as well as measurement of equivalent conicity [3, 4, 6],

– examination of calculation and assessment methods of railway track geometry measurement data executed by track geometry recording cars from the viewpoint of real chord values [5].

Foreign research teams used the methods as follows:

– finite element modelling, static and dynamic approximation [10, 12, 13, 16, 23, 24, 29, 36, 37, 45, 50, 53, 54, 68, 69],

– laboratory tests [2, 13, 21, 22, 24, 25, 27, 39, 52, 54, 56, 57, 65, 66],

– field tests [2, 9, 10, 11, 18, 23, 31, 33, 34, 38, 40, 52, 53, 54, 55, 58, 59, 60],

– calculations based on mathematical and physical theories, i.e. MATLAB [17],

– mathematical computation of degradation and maintenance assumption [41, 42, 43, 44, 51],

– IoT techniques,

– electrical measuring methods [14, 28],

– signal processing for non-destructive testing of railway tracks [59],

– mathematical (statistical) regression analysis and artificial intelligence, as well as artificial neural networks [41, 42, 43, 44].

– The authors mention some relevant results related to laboratory tests from literature review:

– The results of literature [2] indicated that dynamic stresses in bonded insulated joints are able to be reduced nearly 40% in joint bars by a combination of design improvements on insulated joint components. Improved fishplate material properties are expected to lead to considerably reduced risk of bar fatigue failures in track. With improved insulated rail joints the bending stress in the fishplate at its critical middle section was able to be reduced by around 22%. The authors of article [2] published that the usage of forged alloy steel fishplates reduce the risk of fishplate failures especially under fatigue loading. Ceramic end post material as a structural element of a glued insulated rail

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joints lower dynamic compressive fishplate stress by approx. 24% and tensile stress by approx. 17% based on laboratory testing. The completed laboratory tests to compare the improved insulated rail joint including all component level improvements against a standard (normal) insulated rail joint verified that the improved assembly has 15% less deflection, 49% less compressive and tensile stresses on the fishplates [2].

– In paper [13] the edge effect to the wheel/rail rolling contact problem was examined with laboratory tests and validated 3D finite element model that considers contact and material non-linear characteristics. A special test rig with a full-scale wheel was designed to be able to taking into account the rolling contact load on railhead. An image analysis methodology (so called Particle Image Velocimetry, PIV) was applied to specify the vertical, horizontal, as well as shear strains on the rail end face. Common strain gauge method was applied to validate the vertical strain received from the PIV method. A virgin railhead edge demonstrated a notable amount of plastic deformation in the first loading cycle compared to following loading cycles. More than twenty thousand microstrains ratchetting was measured for the hundred loading cycles with both the loaded (approx. 130.7 kN) and unloaded (approx. 50 kN) vehicle wheel loads. Deeper plastic zone was resulted on the rail end face related to the loaded than the unloaded vehicle wheel load. The experimental assembly and laboratory test setup are able to be applied to study the wheel/rail contact (interaction) problem with different rail test samples and loading conditions [13].

– An experimental investigation and improvement of insulated rail joints end post performance were executed in PhD thesis and two papers [21, 22]. The aim of this PhD thesis was to specify the resistance to sliding wear, impact wear, rolling/sliding contact wear, compression wear of five different end post materials with different characteristics against train steel wheel material, as well as the effect of tests parameters and lubrication on these tested materials. The end post materials were classified into thermoplastic materials and thermosetting materials according to melting point temperature. The thesis resulted that the performance of the insulated rail joints can be improved with selection of the optimum end post material. The best choice is the epoxy glass material for end post element based on better resistance during ‘sliding’ tests, as well as better wear resistance with lower temperatures (i.e. without melting) [21, 22].

– Paper [24] introduced an experimental method that ensures measurement of the progressive ratchetting at rail end next to end post. A special test rig was designed for this research. The rig also provided the capability of testing of the wheel/rail rolling contact conditions. The authors measured and analysed the following parameters: e.g. vertical strain variation along depth of unsupported rail end, accumulation of plastic strain, as well as they had to validate their finite element model using laboratory test results. The article pointed out that the unsupported railhead edge within the gap of the insulated rail joint was found to accumulate momentous plastic strain during the passage of each wheel, with the rate of accumulation being the highest during the initial period of the wheel passage. The top corner of the railhead edge is the most vulnerable position [24].

– Experimental modelling of lipping in insulated rail joints and investigation of rail head material improvements were executed in article [25]. Lipping tests of different types of steel rail head over different types of endpost have been performed by rolling and sliding twin disc test machine. Lipping in these laboratory tests has been caused by both the bulk deformation of the steel at the endpost and influenced by the tractive force and ratchetting of the steel at the running surface. Higher steel grades and epoxy glass end post materials resulted the optimum solution (lower plastic deformation during the executed laboratory tests [25].

– Article [27] summarized the results of test series performed with full-scale sections of rail that had been treated by laser cladding (1–2 mm thick layer of high performance material) on the rail head. During laboratory tests wear, lipping of insulated block joints and bending fatigue of clad samples were measured. The wear rate of the clad samples was approx. 78–89% lower than that of the standard R260 (rail steel grade) reference sample. Cladding of either side of an insulated block joint significantly improved its lipping resistance and allows it to withstand c.a. 3 times the energy input into the contact compared to a standard unclad sample. A section of rail clad with martensitic stainless steel was tested with fatigue bending test with five million cycles at a stress range of

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350 MPa (it passed to R260 steel grade). Bend tests were executed regarding to standard prescription of flash but welded rail in the UK [27].

– In paper [39] microstructural changes in the nearness of endposts of insulated rail joints made from both surface coated and uncoated rail were examined using methods of optical and scanning electron microscopy. Damaged insulated rail joints made from pearlitic head hardened rail steel materials were compared with head hardened rail steel laser coated with martensitic stainless steel materials, from those the last mentioned had an increased service life [39].

– Characterizing and inspecting for progressive epoxy debonding were introduced in article [51] related to glued insulated rail joints. Paper [51] deals with detailed manner with the debonding phenomena in the interface between fishplates and rail webs. Measurements showed that epoxy debonding tends to begin at the endpost element near the top edge, bottom edge, or both edges of the fishplate. Debonding can occur on all four rail-fishplate interfaces within a rail joint. The size of the debonded region did not vary considerably between the so called field side (outer side) and the so called gage side (inner side). However, there was a considerable trend for one end of the rail joint to have more debonding than the other end [51].

– Gallou et al. [53] different methods for external reinforcement of insulated rail joint, e.g. strap rails, beams. Usage of strap rails reduced the vertical deformation of a suspended insulated rail joint. This kind of improvement resulted higher deflection than the plain rail. However, the strap rails are recommended as a cost-effective external reinforcement for maintaining the insulated rail joints performance over time. Usage of 39% stiffer I-beam sections reduced the vertical deformation of a suspended insulated rail joint to a higher level than that obtained by strap rails. More robust beams can reduce the deflection of insulated rail joints to a level similar to that of plain rails. The effect of external reinforcement on the reduction of displacement and dip angle of an insulated rail joint is more critical for soft or softer support characteristics. The structural reinforcement reduced the total dip angle of a suspended insulated rail joints for all support circumstances by a considerable level. The total dip angle had not a linear correlation with the stiffness increase [53].

– Buggy et al. [55] dealt with laboratory and field (in-situ) strain measurement methodology using optical fibre Bragg grating sensors. The technique is adequate for measurement of e.g. insulated rail joints (fishplates) or switch blades. The sensors detect the signals during the passage of a tram/train over the sensor location. For the fishplates, a controlled series of investigations was undertaken in which the torque of the fishplate bolts was changed, both in a laboratory and in railway track. Both measurement methods showed and verified that it is possible to measure strain as an indicator of bolt-torque, and wavelet-based assessment of the time series facilitated the use of principal component analysis to classify the signals by bolt-torque. The usage of this technology would allow continuous monitoring of railway track components, offering significant safety and economic benefits over current practices [55].

– Article [56] demonstrates a laboratory test method for determination residual stresses in insulated rail joints with usage of neutron diffraction technique. Neutron diffraction analyses were carried out on the samples in longitudinal, transverse and vertical directions, and on 5 mm thick sliced samples cut by Electric Discharge Machining (EDM). Old (ex-service) rail samples, irrespective of loading conditions and service times, were found to have similar depth profiles of stress distribution [56].

– A reflection based ultrasonic approach was applied to condition monitor glued insulated rail joints through to failure, under the application of a dynamic shear load [65]. The technique monitored the glued interface, a key failure site in glued insulated rail joints, using a normally incident longitudinal ultrasound wave. Measured reflection coefficients showed that the failure of glued insulated rail joint started with the degradation of the glued insulating layer. The results showed that ultrasound can be used to monitor the condition glued insulated rail joints [65].

– Nicoli et al. [66] performed laboratory tests with a lot of types of glue materials of glued insulated rail joints. The authors mainly used common, standard adhesive material tests to characterize glued insulated rail joints' adequacy. The different tests were not intended to give a unique indication in terms of the combination of adhesive, insulator, and surface treatment that guarantee the best over-

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all performance for a real insulated rail joint. Nevertheless, it was observed that one of tested adhesive material had the best apparent shear strength measured with single lap joints, although it did not show the best performances in other tests [66].

The authors' aim is to compare the behavior of polymer-composite fishplated (fishplate type: APATECH, rail joint type so called MTH-AP), as well as control steel fishplated (type GTI and MTH-P) glued insulated rail joints in railway track and determine the exact deterioration process as a function of loading cycles (or elapsed time). The authors' future task is to investigate and perform diagnostic analysis of experimental (with fibre-glass reinforced fishplates) and control (with traditional steel fishplates) glued insulated rail joints from straightness tests and track geometry recording car measurements and determine the variation of state characteristics of these rail joints.

This article is the continuation of the authors previous papers [25, 45, 46, 47]

Methodology

In this chapter the history of authors' research related to laboratory tests is presented. These tests were executed with three pieces of specimens, one specimen for MÁV48 (48.3 kg/m and 48.5 kg/m), one for 54E1 (54.43 kg/m) and one for 60E1 (60.21 kg/m) rail profiles, which assembled by MÁV-THERMIT Ltd. in 2016.

Before starting the laboratory tests, the authors had to determine the laboratory test parameters. It should be mentioned, that there isn't currently valid European or national standard or technical specification for the polymer-composite fishplated glued insulated rail joints, therefore CEN/CENELEC: WG18/DG11 [15] standard was applied, which refers to the steel fishlpated glued insulated rail joints' laboratory tests. The examined formation of glued insulated rail joints with APATECH branded fishplates in railway track are shown in Fig 1.

Fig. 1. Glued insulated rail joints with special fibre-glass reinforced plastic (polymer-composite) fishplates (brand: APATECH) in railway track (authors' photo)

During the first part (Research + Development between 2015-2017 years) of the three-point laboratory bending test series the considered parameters, characteristics, the process of testing were as below.

Static shear tests of glue materials

There were 2 periods of shear test series of glue materials: 54 pieces of glued specimens (c.a. 150-200 mm long rail, 300-400 mm long fishplates glued on both sides) were prepared and they were tested. The laboratory tests were executed with 8 different types of glue materials. Based on the calculated shear strength values the IBI and IAI glue material were chosen for further laboratory tests [25, 45, 46, 47]. The reason that these types were chosen: glue material IBI is commonly applied at Österreichische Bundesbahnen (ÖBB, Austrian Railways) for glued insulated rail joints, glue material IAI had very high shear strength.

Bending tests

During the static three-point bending, fatigue (dynamic) and static bending breakage tests the authors defined the parameters, according to the standard [15], as well as Zimmermann-Eisenmann superstructure calculation method, the values of bending moments were calculated separately for

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different rail profiles depending on the maximal loading force and the supporting interval. The computed values of bending moments are shown in Table 1 (specimens were assembled by MÁV-THERMIT Ltd.). The testing parameters were the followings:

– static three-point bending test without breakage, before fatigue (BF), on supporting bays: 1000, 1200 and 1490 mm,

– vertical load consists of two phases:

  ○ in the first phase: a pre-load is applied that the tested rail joint should IfitI (move) into the desired position,

  ○ in the second phase: a load is applied up to the calculated maximum value (hold this peak load for 2 minutes) and then release it to the unloaded (0) position,

– three-point dynamic bending fatigue test with 3.5 million loading cycles (bays: 1200 mm),

– static three-point bending tests without breakage after fatigue (AF), bays: as mentioned before,

– static three-point bending test until breakage (failure), bay: 1490 mm,

– number of specimens: 9 (length of specimens: 2×850 mm=1700 mm). 3×2 pieces of specimens for each rail profiles that prepared (assembled) by IAI type glue material, and 3 pieces with IBI type glue material,

– the MÁV-THERMIT Ltd. prepared more 3 specimens without glueing for control.

Meanwhile the three-point bending tests (before fatigue and after fatigue) the maximum vertical displacement in middle of the bay (thousandth mm precisely) depends on the maximum force, these parameters were measured and recorded.

Results of these laboratory tests were published in [25].

Table 1

Calculated values of bending moments

Rail profile	Support bay [mm]	Max vertical force [kN]	Bending moment [kNm]
60E1	1 490	114.44	42.63
	1 200	142.10	
	1 000	170.52	
54E1	1 490	109.66	40.85
	1 200	136.17	
	1 000	163.40	
MÁV 48	1 490	93.18	34.71
	1 200	115.70	
	1 000	138.84	

During the 2nd part of the research (additional tests that are supported by the ÚNKP-18-3 New National Excellence Program of the Ministry of Human Capacities) the authors executed more laboratory tests, namely additional (supplementary) three-point bending tests. The considered parameters, characteristics, the process of testing were the followings (Fig. 2.):

– static three-point bending test before fatigue (initial static test, without breakage),

– three-point dynamic fatigue test with 0.5-0.5 million loading cycles (altogether 7×0.5 million cycles, the applied support bay length was 1200 mm for every specimens),

– static three-point bending test with very precise vertical displacement (deflection) measurements after every 0.5 million loading cycles until the final 3.5 million loading cycles (remark: this measurement was performed certainly before the first dynamic tests, too),

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– vertical displacement measurement in 7 different points with symmetric support layout,

– on 13 different support bay values (900…1490 mm, on 50 mm latitude steps),

– from antecedent research: investigation of steel fishplated glued-insulated rail joints that were already bear fatigue tests with 3.1 million loading cycles – execution of additional three-point dynamic bending tests with 0.4 million cycles,

– after 3.5 million loading cycles additional measurements on symmetric support bays with all the rail joint specimens (with polymer-composite and steel fishplated glued insulated rail joints, too, between 600 and 900 mm support bay values),

– after 3.5 million loading cycles additional measurements on asymmetric support bays with all the rail joint specimens (with polymer-composite and steel fishplated glued insulated rail joints, too, between 600 and 900 mm support bay values),

– vertical displacement measurements in 9 different points with symmetric support layout,

– the maximum vertical displacement values were measured at two locations (in the middle of the support bay length, and in the middle of the specimen).

Fig. 2. The 3-point bending test arrangement of the laboratory measurement

The authors give an example for the required time period related to laboratory tests: the value of dynamic bending moment according to 54 rail profile specimens on 1200 mm support bay: F_{min}=5 kN, F_{max}=136.2 kN, f=5 Hz sine signal (M_{max}=40.85 kNm) 0.5 million loading cycles required approx. 27.77 hours. Completion of fatigue test with 3.5 million loading cycles for one specimen is about 194.44 hours.

The goal was to evaluate the more accurate deterioration process of glued insulated fishplated rail joints.

Findings

In the followings additional results of three-point bending tests are introduced.

During the first part of the test-series [25, 45, 46, 47] (before fatigue and after fatigue) vertical displacement in the middle of the bay length as a function of vertical force value were measured and recorded. After the test it was experienced that the vertical displacement values related to applied maximum vertical force values were higher for polymer-composite fishplated glued insulted rail joints than the limit value prescribed for steel fishplated rail joints in standard [15] but the tested specimens were passed the laboratory tests without any problems. So the fatigue tests were done without any crackings, failures and breakages, there was not any visual failure neither on the fishplates nor on the rail end posts.

Symmetric support bay layout

After the the second part of test series (i.e. the additional laboratory tests, supported by ÚNKP-18-3) the sentenced findings are the followings:

– The goal was to evaluate the deterioration process of polymer-composite fishplated glued insulated rail joints as well as steel fishplated glued

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insulated rail joints by detailed and sophisticated laboratory tests.

– Calculated parameters that can be compared to the first (BF) measurement values (from 0.0 to 3.5 Mio. loading cycles).

– Investigation of the change of calculated parameters (ratio: how it has been changed from the first measured data (BF)).

– Analysis of the measured values depending on the applied force vs. vertical deflection (slope of the curves – linear fitted lines). The measured data were represented in graph related to the three rail profiles and loadings (before fatigue test (BF) until 3.5 million loading cycles on 900…1490 mm support bay lengths). Fig. 3 shows average vertical deflection values in the middle of the specimen related to MÁV 48 rail profile on 1000 mm support bay. The separated curve in graph on the right side is related to the non glued (WG, i.e. without glueing) specimen. This graph shows that how much higher deflection values occur if the any adhesive material isn't applied in insulated rail joints with fishplates. Fig. 3 demonstrates that glued insulated rail joints with traditional steel fisplates had much smaller vertical deflections in the middle of the specimen than with special plastic fishplates. Fig 4. illustrates an example for deflection 'curve' for the whole length rail joint specimen.

– Linear regression functions can be fitted to the recorded data series (uploading section until e.g. 90 kN or peak force values), these can be applied to determine the variation of the tangent values (for different cases).

– Calculation of stiffness characteristic parameters which depends on the tangent of the linear regression functions (mentioned above) and the support bay length values (unit: kN/mm/mm). Fig. 5 shows the so far executed measurements and calculated stiffness characteristic values related to 48 rail profile specimens on all support bay lenghts. The graph shows that the highest stiffness value is related to steel fisplated glued insulates rail joint specimens. Curiosity, behavior of all rail joints is quite similar.

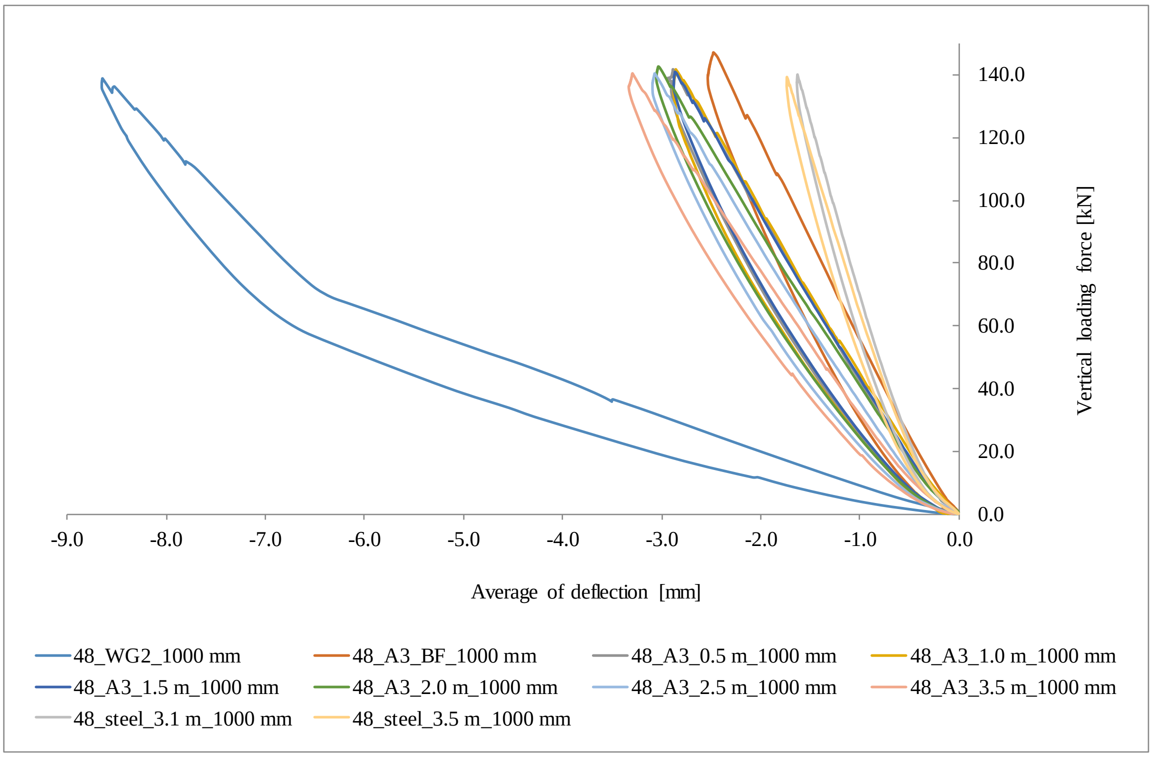

Fig. 3. Average deflection as a function of applied vertical force
(48 rail profile, 1000 mm support bay length)

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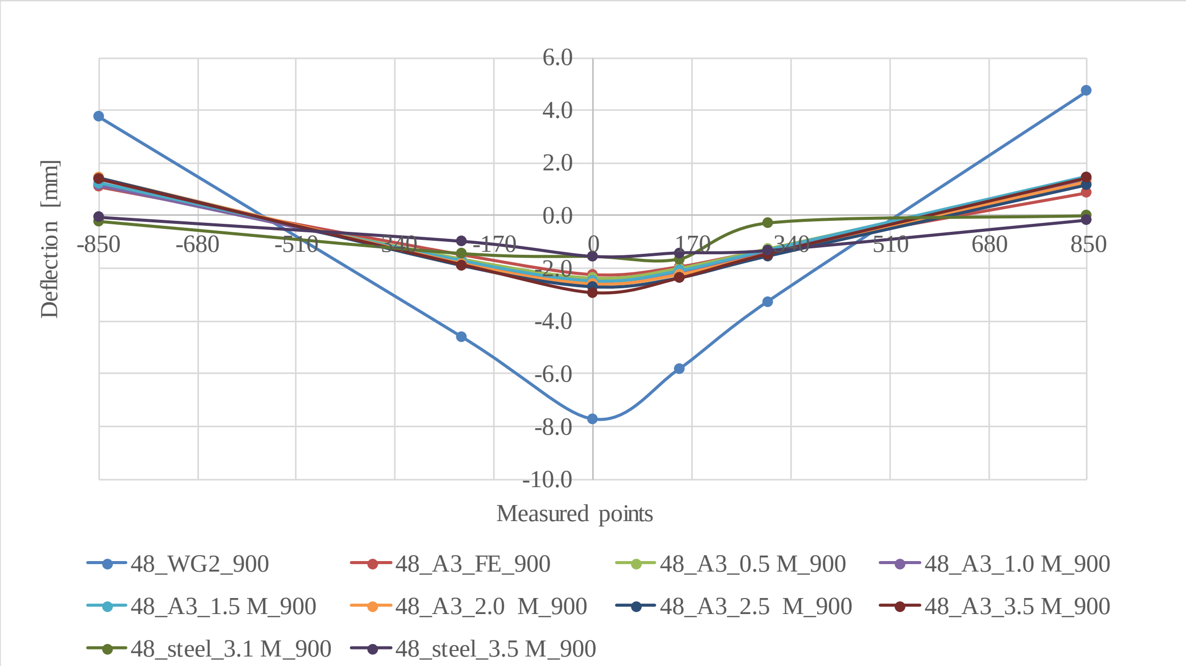

Fig. 4. Deflection 'curve' for the whole length rail joint specimen
(48 rail profile, 900 mm support bay length, symmetric layout)

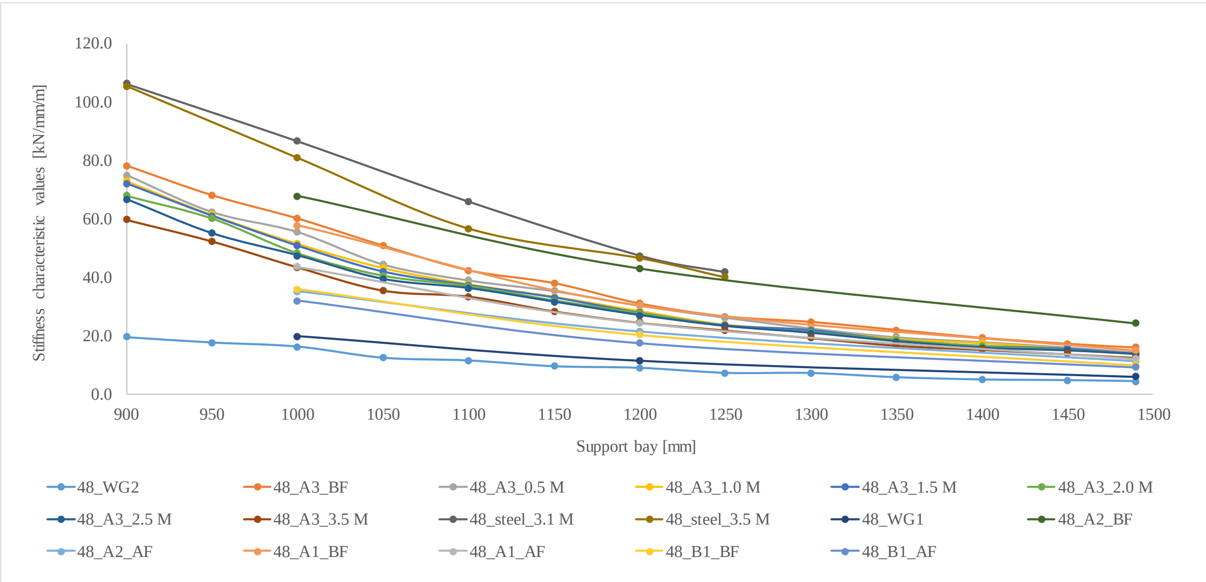

Fig. 5. The stiffness characteristic values as a function of support bay lengths (48 rail profile)

– Representation of values as a function of different support bay lengths, as well as fatigue loading cycles.

– Representation of ratio of stiffness characteristic values, which value depends on the first measured data (before fatigue).

– Depiction of measured vertical displacement values (in 9 different points along the specimens), illustration and calculation of the area below the graphs (i.e. integer, with trapezoid rule) – to be able to check the state change process of specimens according to fatigue loading cycles. The

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area (integer) values were computed from the values below the 'curve' that is illustrated in Fig. 6 for every support bay length value related to specimen with 48 rail profile with applied maximum vertical force. Determination of the ratio relative to the first measured data related to every support bay length, it seems there is linear correlation between this parameter and the support bay length values for all three rail profiles.

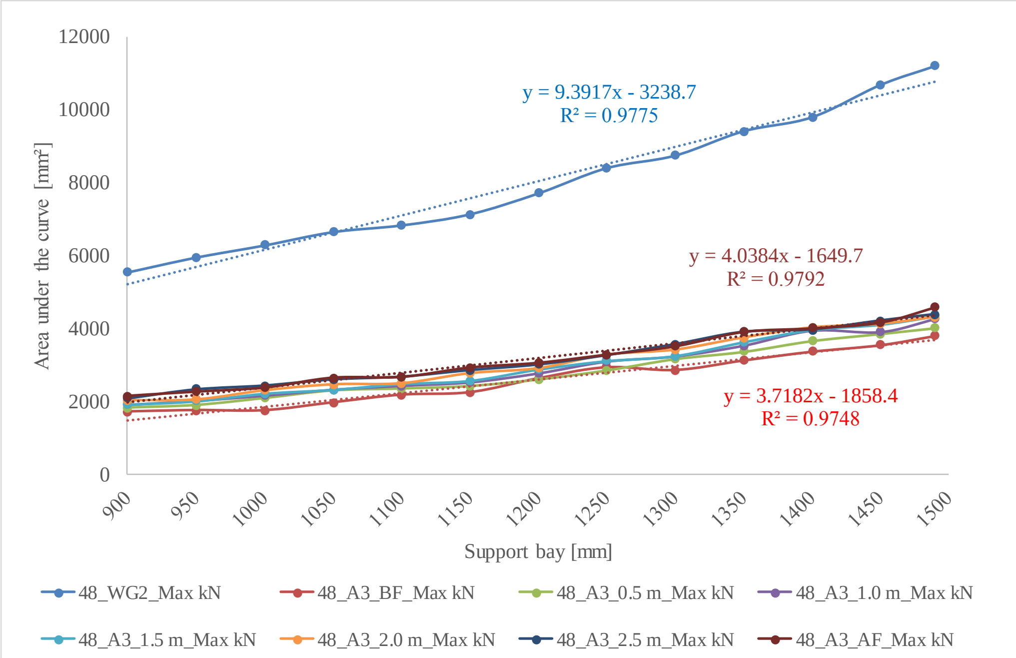

Fig. 6. The calculated area values under the curve as a function of support bay lengths (48 rail profile specimen)

Asymmetric support bay layout

After 3.5 million loading cycles bending tests were performed on asymmetric support bay layouts for all the rail joint specimens (polimer-composite and steel fishplated joints, too) between 600 and 900 mm. Measurements were executed similarly to the symmetric layout, however, this (asymmetric layout) was measured only after 3.5 million fatigue loading cycles. The values were calculated and compared relatively to the results from symmetric layout after 3.5 million loading cycles. Values were recorded for three different support layouts per support bay length values (e.g. on 600 mm support bay layout the arrangements from the middle of the specimen were the following: 150-450 mm, 200-400 mm and 250-350 mm).

Originality and practical value

The role of the glued insulated rail joints with fishplates is to ensure the continuity of rails without horizontal and vertical steps, avoiding the directional 'refraction' between rail ends. Rail joints are the weak points of the track, because their fishplates can compensate only the 60% of the moment of inertia of the rail. Wheels hits the following rail end during through-rolling the rail end gap, which is disadvantageous for the whole railway super- and substructure, too. Dynamic effects are much higher in case of vertical and/or horizontal steps.

Insulated rail joints can be applied in suspended and supported joints depending on their type in case of value of sleeper space and wheel load prescribed by manufacturer. High tensile strength bolts with great forces are used to 'press' fishplates and rail together. In this way high friction force can be achieved, it causes that the high tensile forces cannot open the rail joints. Plastic profile lining plate (end post) is built between rail ends. Insulated rail joints can be produced in plant as prefabricated elements with given length rails, as well as on the field, where they are assembled.

The usage of glued insulated rail joints with glass-fibre reinforced plastic fishplates is able to eliminate the electric fishplate circuit and early fa-

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tigue deflection and it can ensure the isolation of rails' ends from each other by aspect of electric conductivity.

After the first series of laboratory tests, rail joints for field tests were manufactured with usage of 'A' type glue material. The polymer-composite fishplated glued insulated rail joints and the assigned control glued insulated rail joints (for comparison) were built-in the track in four different locations, with three different rail profiles, for three different speed categories (Biatorbágy, Tatabánya, Győr, Lébény-Mosonszentmiklós railway stations, every is in the MÁV No. 1 main railway line, Kelenföld-Hegyeshalom state border). According to railway maintenance experiences of Hungarian Railways (MÁV) and Raaberbahn, Győr-Sopron-Ebenfurth Railway (ROeEE, in Hungarian: GYSEV), glued insulated steel fishplated rail joints need a lot of maintenance source (money and work) due to rail deformations (settlements). Usage of plastic fishplated glued insulated rail joints can be solution to the problems of keeping the construction specifications in place during installation into railway track.

Conclusions

The authors represented the results of additional laboratory tests on glued insulated rail joints with traditional steel fishplates, as well as fibreglass reinforced plastic fishplates. The aim of this research was to determine the ultimate lifetime of the investigated glued insulated rail joints by laboratory three-point static and dynamic bending tests.

The authors sentenced the following important facts derived from this part of their research.

The authors tried to investigate and analyse the conformity of the glued-insulated rail joints with glass-fibre reinforced plastic fishplates (brand of fishplates: APATECH) according to laboratory and field tests. Glue material type "AI was chosen for the detailed laboratory tests series, as well as for field tests. This type of adhesive material had very high shear strength during laboratory tests, and it ensured good initial results from bending tests, as well as axial pulling tests.

The main goal should be to compare the behaviour of different types of glued insulated rail joints (i.e. traditional steel fishplated one, as well as plastic fishplated one). The traditional steel fishplated glued insulated rail joints are commonly applied at most Railways/Railway Companies, but there are some problems with them, e.g. the so called short circuit due to rail ends' plastic deformation (e.g. ratchetting, etc.), or failure of end posts, or electric insulation problem between fishplates and rails, breakage, etc. Glass-fibre reinforced fishplates are produced of electric insulation material, so no further insulation layer is needed. It should be mentioned that the expected deformation of glued insulated rail joints with this kind of plastic fishplates are resulted with higher deformation values (vertical deflections, settlements). This fact was verified by the authors' measurement results.

The test series of the authors consisted not only laboratory tests [25] but field tests (in real railway track [25, 45, 46, 47]).

The authors would like to define the accurate deterioration process of the investigated glued insulated rail joints as a function of loading cycles. They applied three different rail profiles, many support bay length values, as well as symmetric and asymmetric support bay layouts, too. The laboratory dynamic fatigue tests are useful because they can simulate loading of many years (e.g. the applied 3.5 million loading cycles means more than 5 years related to the Hungarian No. 1 main railway line, Kelenföld-Hegyeshalom state border), but it needs only 194.44 hours in the laboratory, as well as laboratory tests ensure (ideal) controlled and regulated test conditions.

The authors determined in [47] that the glued insulated rail joints with Apatech branded fishplates – on the basis of railway track measurements – are not a general solution for replacing the steel fishplated glued insulated rail joints in the CWR railway tracks. The authors think that not only static but dynamic railway track measurements of glued insulated rail joints as well as their assessment can be a very interested research direction in the future.

The authors applied ultimate 3.5 million loading cycles during their laboratory tests, but it has to be mentioned that the European standard for steel fishplated glued insulated rail joints requires only 3.0 million. It has to be mentioned that e.g. in Austria this requirement is stricter than the European standard, i.e. the number of prescribed minimum fatigue loading cycles is 5.0 million [67].

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More parameters were calculated in this article from the results of three-point bending tests:

– stiffness characteristic value (unit: kN/mm/mm),

– area under the curve (mm2), so called integer.

These parameters and their change were defined as a function of loading cycles, support bay values for different rail profiles, as well as for steel and glass-fibre fishplated glued insulated rail joints.

The presentation of the measured results can be performed by their original values, as well as ratio to the measured value for the same support bay length and same rail profiles, glued specimen, before fatigue test state. Or in other case, it can be compared to the cases, without glueing. In this way very expressive graph can be prepared.

Summarizely, glueing ensure approx. 2.5 times differences in the calculated parameters (compared to ‘without glueing’ cases, of course), it means glueing reduces elastic deformation (for the same given loading) related to insulated rail joints with glass-fibre reinforced approx. 2.5 times.

It should be mentioned that the increasing loading cycles raise the evolved deformations compared to the initial stage (before fatigue), e.g. glued insulated rail joint with 48 rail profile resulted with approx. 80%, with 54 rail profile 70%, as well as with 60 rail profile 90% is the stiffness characteristic value after 3.5 million loading cycles.

In case the stiffness characteristic values after 3.5 million loading cycles are calculated for steel fishplates as well as plastic fishplates, the results are the following related to 900 and 1200 mm support bay length values correlated to glued insulated rail joint specimens with plastic fishplates, before fatigue test:

- 900 mm support bay length:
  - 48 rail profile:
    - steel fishplated joint: +35%,
    - plastic fishplated joint: –24%,
  - 54 rail profile:
    - steel fishplated joint: +64%,
    - plastic fishplated joint: –31%,
  - 60 rail profile:
    - steel fishplated joint: +2%,
    - plastic fishplated joint: –36%,
- 1200 mm support bay length:
  - 48 rail profile:
    - steel fishplated joint: +50,6%,
    - plastic fishplated joint: –21%,
  - 54 rail profile:
    - steel fishplated joint: +59%,
    - plastic fishplated joint: –33%,
  - 60 rail profile:
    - steel fishplated joint: +35%,
    - plastic fishplated joint: –9%,

It can be concluded that the laboratory tests ‘use’ simple two-supports mechanical structure model, but in reality the mechanical structure model is much more complicated, e.g. continuous beam with more supports that can elastically or plastically settle. This kind of model is e.g. Zimmermann or the enhanced Zimmermann-Eisenmann model. In case continuous beam with more rigid supports is considered, the maximum bending moment decreased with 24.5% (i.e. Winkler model, $M=0.1888\times F\times L$, where ‘M’ is the bending moment in kNm unit, ‘F’ is the vertical force in kN unit, and ‘L’ is the support bay length in m unit; correlated to the $M=0.25\times F\times L$ equation).

According to the measurement results it can be an opportunity to be able to calculate deflection values, stiffness characteristic values, or ‘area under the curve’ values for variant support bay length or variant loading cycles. It should be mentioned that these values are able to be only ‘prognosed’ values.

In case the stiffness characteristic value is considered (as a function of loading cycles), there can be determined two separate sections related to plastic fishplated glued insulated rail joints:

– 1st: 0…1.0 million loading cycles,

– 2nd: 1.0…3.5 million loading cycles.

In the 1st section the tangent of the linear regression function is much higher than in the 2nd section, where the ‘lines’ tend to be plain. The tangent values of the graphs (in case the stiffness characteristic value in kN/mm/m unit) for 48 and 54 rail profiles are approx. –0.07, for 60 rail profile is approx. –0.03. It results that glued insulated rail joints with fibre-glass reinforced plastic fishplates with 60 rail profiles are 2.33 times ‘stiffer’ than the other two ones – related to stiffness characteristic value, considering applied loading cycles.

In case Fig. 4 is considered, it can be stated that the glued insulated rail joints with fishplated results a so called ‘knuckle’ in the rail, because the deflection ‘curve’ has a ‘refraction point’ in the

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line of vertical force, in this way the continuous beam structure model isn't the best solution for modelling and calculations.

The authors sentence that at this stage of the research (given stage of data processing of results) it can't finish with accurate result for the lifetime of the tested glued insulated rail joints. However, it can be seen that the failure won't be/isn't assumed in the next some 100.000 loading cycles, maybe nor in the next some million loading cycles.

Based on the field tests there were no structural and geometric problems, signal and interlocking interruptions during the three-year observation period, or any other situation with inspected glued-insulated rail joints.

The authors would like to continue their research in the determined direction and publish the new results in papers.

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РЕЗУЛЬТАТИ ЛАБОРАТОРНИХ ВИПРОБУВАНЬ КЛЕЙОВИХ ІЗОСТИКІВ ІЗ ТРАДИЦІЙНИМИ СТАЛЕВИМИ Й ПОСИЛЕНИМИ СКЛОПЛАСТИКОВИМИ НАКЛАДКАМИ

Мета. Автори передбачають більш точно оцінити процес зносу клейових ізольованих рейкових з’єднань із полімерно-композитними і сталевими накладками за допомогою лабораторних випробувань. **Методика.** Лабораторні випробування проводилися за допомогою результатів вимірювань статичних і динамічних (втомних) випробувань на триточковий згин клейових ізольованих рейкових стиків, посилених склопластиковими полімер-композитними накладками (марка APATECH). У ході дослідження були проведені статичні випробування на триточковий згин рейкових стиків зі сталевими й полімер-композитними накладками. Для випробувань використані зразки трьох різних профілів (MÁV48, 54E1 (UIC54) та 60E1 (UIC60) після 3,5 млн циклів навантаження (процес зносу перевірено після кожних 0,5 млн циклів). Перед проведенням випробувань на втому зразки було виміряно на 13 різних значень. **Результати.** У наш час проводять дослідження посилених склопластикових і сталевих рейкових з’єднань (триточкові статичні й динамічні випробування на вигин). Із урахуванням цих досліджень процеси механічного руйнування було визначено шляхом порівняння значень вигину з вихідними значеннями (тобто до випробувань на втому). За допомогою аналізу результатів вимірювань отримані відмінності щодо обох типів клейових ізольованих рейкових з’єднань зі сталевими й полімер-композитними накладками. **Наукова новизна.** У результаті дослідження вивчено застосування нового типу клейових ізольованих рейкових стиків і визначено остаточний термін служби цих рейкових з’єднань, зокрема, скільки часу їх можна безпечно використовувати на залізничній колії без пошкоджень. У міжнародній літературі ця сфера клейових рейкових стиків не була досліджена. **Практична значимість.** Рейкові стики, посилені склопластиковими накладками, а також ІконтрольніІ ізольовані клейові рейкові стики зі сталевими накладками були вбудовані в залізничну лінію між державним кордоном Келенфёльд і Хед’єшалом в Угорщині в трьох різних місцях. У цій статті процес зносу клейових ізольованих рейкових стиків продемонстровано тільки за допомогою лабораторних випробувань на вигин.

Ключові слова: лабораторні випробування; склопластик; накладка; рейковий стик; руйнування

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РЕЗУЛЬТАТЫ ЛАБОРАТОРНЫХ ИСПЫТАНИЙ КЛЕЕВЫХ ИЗОСТЫКОВ С ТРАДИЦИОННЫМИ СТАЛЬНЫМИ И УСИЛЕННЫМИ СТЕКЛОПЛАСТИКОВЫМИ НАКЛАДКАМИ

Цель. Авторы предполагают более точно оценить процесс износа клеевых изолированных рельсовых соединений с полимерно-композитными и стальными накладками с помощью лабораторных испытаний. **Методика.** Лабораторные испытания проводились с помощью результатов измерений статических и динамических (усталостных) испытаний на трехточечный изгиб клеевых изолированных рельсовых стыков, усиленных стеклопластиковыми полимер-композитными накладками (марка APATECH). В ходе исследования были проведены статические испытания на трехточечный изгиб рельсовых стыков со стальными и полимер-композитными накладками. Для испытаний использованы образцы трех различных профилей (MÁV48, 54E1 (UIC54) и 60E1 (UIC60) после 3,5 млн циклов нагрузки (процесс износа проверялся после каждых 0,5 млн циклов). Перед проведением усталостных испытаний образцы были измерены на 13 различных значений. **Результаты.** В настоящее время ведутся работы по исследованию усиленных стеклопластиковых и стальных рельсовых соединений (трехточечные статические и динамические испытания на изгиб). С учетом данных исследований процессы механического разрушения были определены путем сравнения значений изгиба с исходными значениями (то есть до испытаний на усталость). С помощью анализа результатов измерений получены отличия по типам клеевых изолированных рельсовых соединений со стальными и полимер-композитными накладками. **Научная новизна.** По результатам исследования изучено применение нового типа клеевых изолированных рельсовых стыков и определен окончательный срок службы данных рельсовых соединений, в частности, сколько времени их можно безопасно использовать на железнодорожном пути без повреждений. В международной литературе эта область клеевых рельсовых стыков не была исследована. **Практическая значимость.** Рельсовые стыки, усиленные стеклопластиковыми накладками, склеенными смолой, а также IконтрольныеI изолированные клеевые рельсовые стыки со стальными накладками были встроены в железнодорожную линию между государственной границей Келенфёльд и Хедьешалом в Венгрии в трех разных местах. В данной статье процесс износа клеевых изолированных рельсовых стыков продемонстрирован только с помощью лабораторных испытаний на изгиб.

Ключевые слова: лабораторные испытания; стеклопластик; накладка; рельсовый стык; разрушение

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