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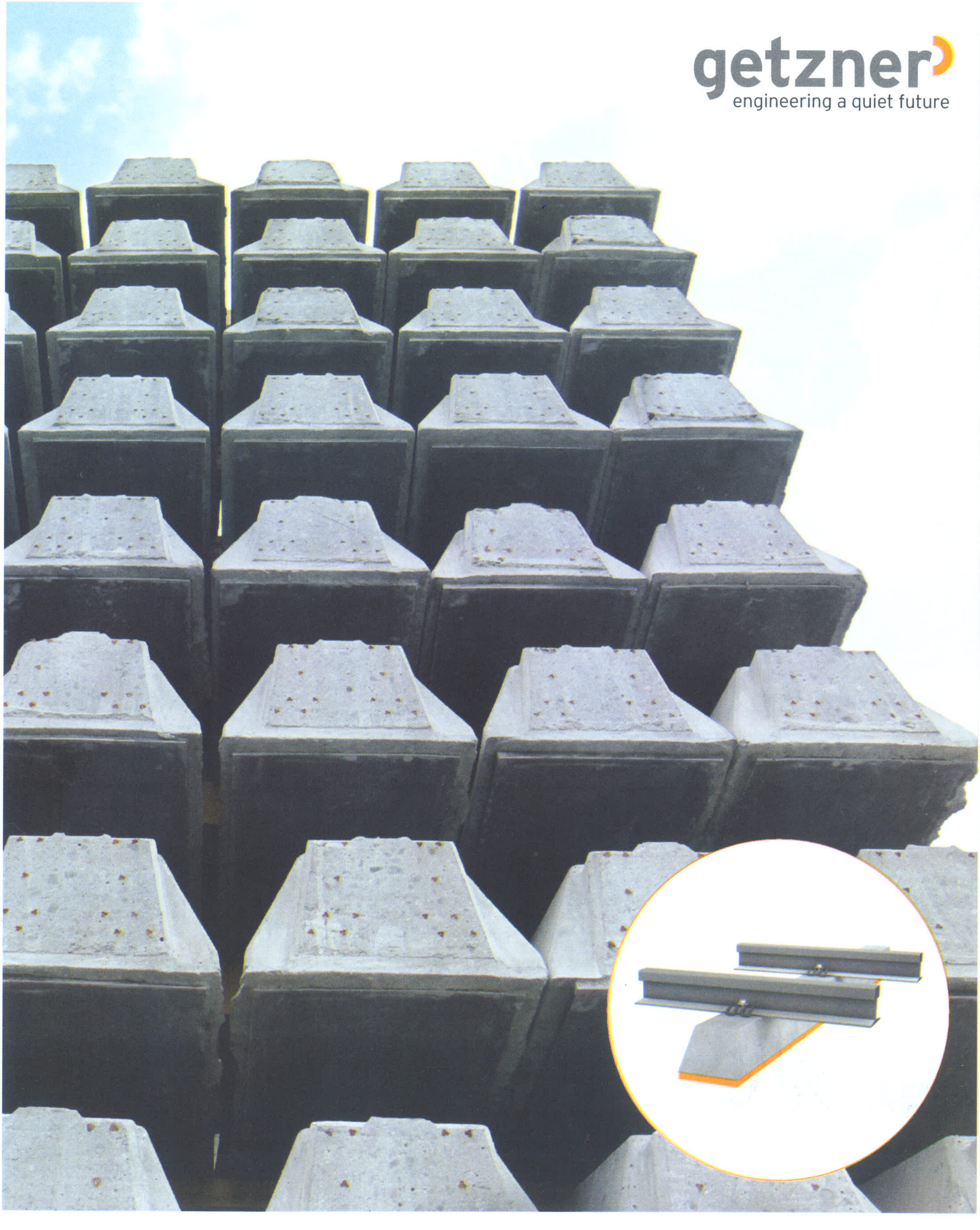

# Pushing the limits of ballasted heavy-haul railway track by means of high-strength under-sleeper pads made of a specially developed PUR

Conventional ballasted heavy-haul railway track, due to the high axle-loads and high tonnages of traffic borne, is subjected to extremely high stresses, which leads to a deterioration in the quality of the track installations, including the ballast. In order to minimise track maintenance demand and, thus, optimise track availability, the use of high-quality track components is of great importance. The latest generation of under-sleeper pads (USPs) made of Sylomer®, developed by Getzner Werkstoffe GmbH, which feature an ideal combination of elastic and plastic properties, provide an optimum load distribution in the track, as well as a reduced sleeper/ballast contact pressure. As proven by extensive laboratory and field tests, this leads to a higher ballast quality sustainability.

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*Fig. 1: White spots – an indication of ballast destruction (top), broken rail clips (left) and sleeper cracking (right), resulting from excessive dynamic traffic loading*

## HEAVY-HAUL RAILWAY TRAFFIC AND ITS NEGATIVE IMPACT ON TRACK QUALITY

One definition of heavy-haul railway lines describes it as lines that carry 40 MGT or more of traffic per annum, independent of the type of traffic borne, i.e. passenger, freight, or mixed [1]. The term heavy-haul railway lines is also used to describe lines that carry traffic with axle loads from 25 t upwards. This high traffic tonnage and axle loading is placing high demands on the track and its components. Besides broken rail clips and sleeper cracking, also ballast quality deterioration, emanating from the sleeper/ballast contact area, may occur – one of the main factors that lead to a shortening of the service life of track installations (Fig. 1). Especially in places where there is a discontinuity in an otherwise highly uniform track, e.g. in transition zones from an open-line track section to a bridge structure, ballast grains are prone to fracture and pulverisation – white spots are a clear sign of this (see Fig. 1), due to a high increase in dynamic loading in these locations.

The implementation of high-quality under-sleeper pads (USPs), often in conjunction with suitable rail pads, can effectively counteract this negative impact.

## BENEFITS OF USING UNDER-SLEEPER PADS

Following the introduction of hardened rail steels and prestressed concrete sleepers, the ballast has become the weakest link in the railway track. As is well known, the use of sleeper padding can significantly help to protect the ballast. Under-sleeper pads, which are implemented as a flexible spring layer underneath the sleepers, increase the sleeper/ballast contact area from 2-8% (without USP) to over 30% (with USP). It has already been widely demonstrated that a larger sleeper/ballast contact area leads to an improvement in load transmission to the ballast bed and a reduction in stress on the subgrade. As a result, ballast grain fracturing due to overloading is prevented and track settlement is minimised. Also, the formation of void areas underneath the sleepers is positively countered.

Since 2001, in order to quantify the long-term effect of padded sleepers, extensive studies have been conducted to measure the rate of quality deterioration of track featuring under-sleeper pads [2]. The track sections studied have clearly demonstrated the positive impact of implementing under-sleeper pads under different conditions, as all the padded sections have shown to have a significantly lower track quality deterioration rate. Even on track sections with a reduced ballast bed thickness, track tamping intervals have at least doubled. The implementation of under-sleeper pads leads to a significant reduction in maintenance demand and, thus, life-cycle costs (LCC) [3], and to a higher track availability.

Today, under-sleeper pads are implemented, in order to achieve:

- a reduction in track settlement in all types of ballasted track structures;
- a reduction in the occurrence of rail corrugation in tight curves;
- an adjustment of track stiffness in areas with a reduced ballast bed thickness;
- an improvement of transition zones between different types of track structure;
- a mitigation of vibration;
- an avoidance of void areas underneath sleepers;
- a levelling of differences in deflection within turnouts.

## A NEW USP WITH AN IDEAL COMBINATION OF PLASTIC AND ELASTIC PROPERTIES FOR HEAVY-HAUL TRACK

The considerable stress imposed on heavy-haul railway track necessitates the use of, on the one hand, under-sleeper pads with highly plastic properties that allow the ballast grains to become embedded as gently as possible. Whereas, on the other hand, in order to achieve an ideal load distribution in the track, under-sleeper pads with highly elastic properties that retain their elasticity in the long term, even when subjected to decades of stress, are required – quite a challenge for materials scientists.

Not all materials are equally suitable. One material that has been proven to be extremely tough and durable is Sylomer®, which is made from a special polyurethane (PUR). In PUR production, a diverse range of properties can be adjusted to meet desired requirements by mixing reactive ingredients. Polyol and isocyanate are the main components by proportion, having a significant impact on the mechanical properties and comparatively high tensile strength of PUR. In the development of under-sleeper pads for the protection of ballast of heavy-haul railway track, an optimum mixing ratio and the right production process are critical, in order to achieve a balanced ratio of elastic and plastic properties.

Getzner Werkstoffe GmbH has met this challenge, in that this company, following decades of research and development, has successfully developed an under-sleeper pad made of Sylomer® that, featuring an ideal combination of plastic and elastic properties, can cushion the extremely high loads that heavy-haul railway track is subjected to, thereby achieving an impressive technical performance (Fig. 2).

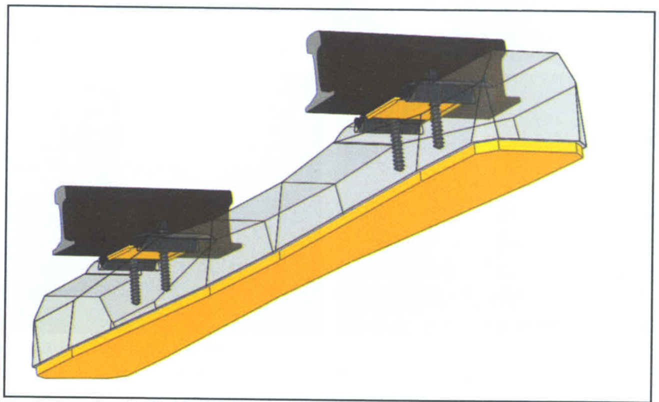

*Fig. 2: Ballast protection provided by polyurethane under-sleeper pads*

## EXTENSIVE LABORATORY AND FIELD TESTING OF THE UNDER-SLEEPER PADS MADE OF SYLOMER®

The under-sleeper pads made of Sylomer® have undergone extensive laboratory and field testing as regards fatigue strength, ballast contact pressure and track settlement behaviour, as alluded to in the following.

### Fatigue strength

The fatigue strength of the newly developed under-sleeper pad was tested in accordance with [4], on a large test rig at Getzner Werkstoffe GmbH (Fig. 3), which allows the simulation of maximum traffic loading generated by the passage of heavy-haul trains [5]. During the tests, factors such as forces exerted when negotiating curves, track bed quality and increased travelling speeds, which result in an increase in dynamic forces, were taken into account, in that the applied static axle load of 36 t was increased in line with these additional dynamics by a factor of 1.52.


*Fig. 3: The test rig of Getzner Werkstoffe GmbH that was used for high axle-load, heavy-haul railway traffic simulation*

A long-term fatigue test was conducted. For this, the under-sleeper pad to be tested was attached to the underside of a concrete specimen measuring 300 mm x 300 mm, which represented the sleeper. The attachment of the test material to the concrete was achieved using a plastic mesh, half of which was inserted into the concrete and the other half into the under-sleeper pad. The long-term test was carried out for a ballast bed thickness of 30 cm. In accordance with [4], the test was conducted in two load stages at a test frequency of 5 Hz, i.e.:

— load stage I, which embraced 5 million load cycles;

— load stage II, which embraced a further 3 million load cycles.

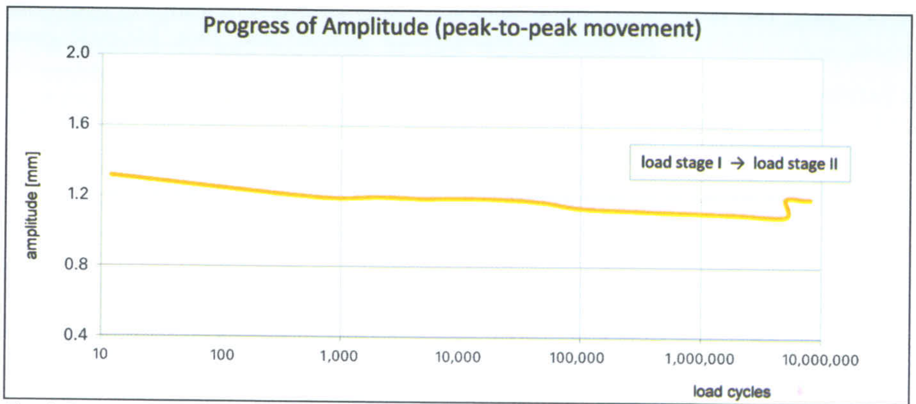


*Fig. 4: Progression of vibration amplitude (peak-to-peak movement) resulting from the long-term fatigue test performed on the test rig of Getzner Werkstoffe GmbH*

Thus, over a continuous period of 3.5 weeks, the under-sleeper pad underwent a total of 8 million load cycles. In Fig. 4, the resultant progression of vibration amplitude is shown.

As can be observed from Fig. 4, at the end of the loading period, still a vibration amplitude of 1.2 mm was measured despite the extremely long-term loading the under-sleeper pad had been subjected to.

*Fig. 5: At the end of the long-term fatigue strength test, the ballast grains remained embedded in the PUR material*

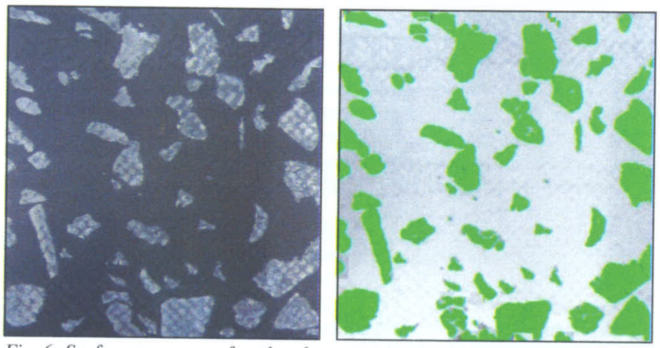

*Fig. 6: Surface structure of under-sleeper pads with ballast indentations (left) – digital analysis yielded a 25-33% ballast contact area (right)*

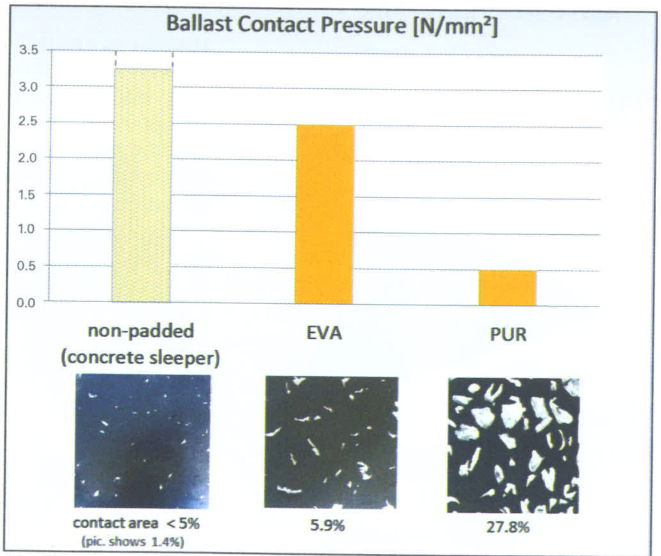


*Fig. 7: Average ballast contact pressure underneath sleepers: a comparison of 'non-padded', 'EVA-padded' and 'PUR-padded' concrete sleepers*

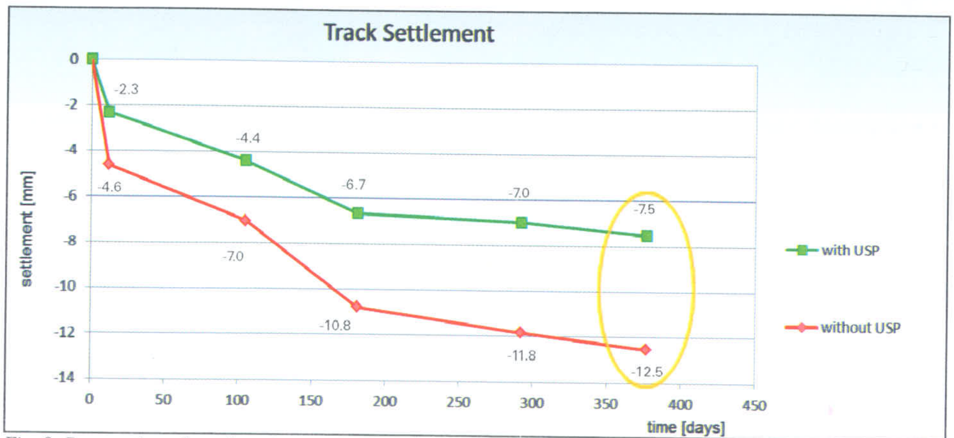


*Fig. 8: Progression of track settlement measured over a period of 377 days – with and without USP*

Further, at the end of the test, it was found that the padding exhibited no signs of cracks, perforations or punctures, despite the extremely high stress to which it had been subjected. The ballast grains had embedded themselves in an ideal manner to a maximum depth of about 80% of the thickness of the padding (Fig. 5). Overall, the under-sleeper pad had passed the long-term fatigue test in an outstanding way due to the excellent properties of the PUR material.

**Ballast contact pressure**

The plasticity of under-sleeper pads allows the top ballast layer to embed itself in the padding material. This is a very important safety-relevant effect, especially as regards lateral track resistance. Investigations have shown that, in general, the lateral resistance of padded concrete sleepers is higher than that of non-padded ones [6]. During the development of the new PUR material, it was clear that track stability was never to be negatively affected in any way [7].

The main benefit afforded by the elasticity of the padding material is the more homogenous load transmission to the ballast bed that is effected. Getzner Werkstoffe GmbH has developed a proprietary digital analysis method for quantifying the USP/ballast contact area quickly and very accurately, which has yielded the new PUR material to have a contact area of 25-33% (see also Fig. 6).

In Fig. 7, the results of a comparative test of ballast contact areas of non-padded, ethylene vinyl acetate (EVA) padded and PUR-padded concrete sleepers (all of the same stiffness), which all underwent an identical long-term fatigue test, with the same nominal material bedding modulus, are given. As expected, the contact area in the case of non-padded sleepers is the smallest (in the test 1.4%, generally it is < 5%), that of the EVA-padded ones is in the middle (5.9%), whereas the PUR-padded ones demonstrate the largest contact area (27.8%).

The main parameter that affects ballast contact pressure is the effective ballast contact area of the sleeper: the larger the ballast contact area, the more uniform the load transmission is and the smaller the ballast contact pressure on the track is (see also Fig. 7).

**Track settlement reduction**

The effect of the Sylomer® sleeper padding material has been evaluated in a large number of field tests [8]. For this, the long-term behaviour of track sections equipped with semi-plastic PUR under-sleeper pads and sections without under-sleeper pads were compared, by recording their track settlement behaviour by means of precision levelling.

In Fig. 8, the average track settlement progression, measured for both track sections with USP and without USP, is shown. As can be observed, after just 377 days, a clear trend became visible: in the non-padded sections, the average track settlement had reached 12.5 mm, whereas in the sections padded with USP, the track had only settled by an average of 7.5 mm.

The latter means that track settlement was more than 65% higher in the non-padded ballasted track sections than in the sections with USP. This positive result perfectly mirrors the experience gained in other USP installation situations, despite the relatively short observation period.

The test track sections with under-sleeper pads have demonstrated a far more homogeneous track bed quality which, in some cases, can even be observed with the naked eye (Fig. 9).

*with USP* *without USP*

*Fig. 9: Track with under-sleeper pads (left) and without (right)*

## CONCLUSIONS

In this article, an under-sleeper pad made of Sylomer® has been presented that features an ideal combination of elastic and plastic properties, which provides an optimum load distribution in the track, as well as a lower contact pressure between the sleeper and the upper ballast layer, thus offering a high level of ballast protection. This new polyurethane under-sleeper pad has successfully undergone extensive laboratory and field testing. For instance, long-term tests have been performed without the under-sleeper pad having shown any sign of material damage.

Heavy-haul railway track, which is subjected to very high stresses, may very much benefit from the use of these new PUR under-sleeper pads, as due to the increase in sleeper/ballast contact area that is provided, less track settlement occurs, resulting in a track bed of a higher quality, thus reducing track maintenance demand and life-cycle cost (LCC), and increasing track availability. With such innovative developments in the field of elastic track components, the design of the traditional ballast superstructure could be sustainably improved.

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