Concrete Slab Arris Protection

Product Performance Validation

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Abstract

The demands placed on concrete floors slabs within a modern logistics facility are significant, and as the technology used in the logistics industry further develops these demands will only increase. The floor must be durable to ensure that building users can operate at maximum efficiency.

The weakest elements of any concrete floor slab are joints contained within it. AlphaJoint® has been protecting joints in concrete slabs for over 10 years, and a study carried out to assess the performance of AlphaJoint® has shown that it does not always protect the concrete slab sufficiently. The materials handling equipment used within a logistics warehouse can also become damaged as a result of repeatedly trafficking AlphaJoint®. Permaban Eclipse® and Permaban Signature® have been developed to overcome these issues.

This document outlines a test methodology used to validate the long term performance of Permaban Eclipse® and Permaban Signature®. The test method itself is validated using Alphaljoint® test results that are compared to the in-situ behaviour of AlphaJoint® observed throughout the last 10 years.

Recommendations are made as to the most appropriate products to be used in the construction of new logistics facilities so that their future operational efficiency is not threatened by the performance of the floor slab.
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1 Introduction

The demands of modern logistics warehouses have changed in the last two decades. Central logistics facilities offer unprecedented levels of supply chain fulfilment and the operational efficiency of a warehouse is a major key performance indicator in the logistics industry. The speed in which the logistics world operates is also evident during the construction phase of a warehouse and today new facilities are built in record time.

An important milestone during the construction phase of any new logistics facility is the installation of the concrete floor slab. A modern, mechanical approach to the construction of a floor slab means that handover of a newly built facility to the occupier is now faster than ever before. [1] Arguably the most important element of the facility, the concrete floor slab is the platform on which all operations within the building take place. The concrete floor slab must be durable and of low maintenance to ensure that the required operational efficiency levels of the building are achieved.

Modern methods of construction mean that several thousand square metres of concrete floor area can be laid in one continuous operation [1]. The intersection of two separate areas of a concrete floor is known as a ‘joint’ and the nature of the construction methods used today means that, long term, a joint will typically be a 20mm (or greater) gap between two separately constructed areas of a concrete floor.

Joints in a modern, well-constructed concrete floor are the single weakest part of the floor and left unprotected, the vulnerable concrete slab joint arris is likely to be damaged when trafficked by materials handling equipment, as the small hard wheels of pallet trucks and other materials handling equipment (MHE) fall into the joint and subsequently impact the concrete arris when trafficking across the floor.

Permaban armoured joints have been protecting concrete slab joint arrises for almost 15 years. In 2002, the development of arris protection systems culminated in the launch of Alphaloint®, a leave-in-place steel formwork system that includes a steel profile to support and armour the vulnerable concrete edge found in formed contraction joints within concrete floor slabs.

For the last 10 years, Alphaloint® has been installed in almost every large logistics warehouse facility built in the UK to provide “joint armouring” to the concrete floor slab. During this time, follow-up visits and inspection work have been carried out on tens of thousands of metres of Alphaloint® to assess the long term, in-situ performance when trafficked by MHE.

Alphaloint® has, in general, protected the concrete slab joint arris against damage from MHE. However, the small hard wheels typically found on pallet trucks and other similar equipment are prone to deterioration as a result of repeatedly trafficking the steel “joint armouring” profile found in Alphaloint®. Logistics facility users have also experienced issues such as increased wear of gearboxes and other mechanical components within MHE as a result of trafficking repeatedly across this steel section.

There have also been instances when deterioration of the concrete, or spalling, behind the steel “joint armouring” has been noted, particularly in high traffic areas within a logistics facility such as transit aisles, internal doorways and dock leveller zones, as shown in Figure 1.1. Without repair, the spalling joint arris shown will quickly deteriorate further becoming unsuitable for trafficking. The operational efficiency of the building will be reduced as MHE seek alternative routes through the facility, while remedial work will further disrupt the operation of the building.

Figure 1.1 – Spalling of concrete behind Alphaloint®

Permaban has developed new products to overcome the issues that have been observed over time with Alphaloint®. Prior to launching these new products, in-house testing was conducted on each product to
understand the long-term behaviour of the products once installed in a concrete floor slab, validating the product performance offered long term to ensure the most efficient operation of a logistics facility.

This document outlines the test methodology used and discusses the results observed, drawing conclusions about the performance of each product and sets recommendations for the most appropriate installation location within a logistics warehouse facility, balancing product cost against long term performance.
2 Permaban Joint Arris Protection Systems

Permaban systems combine leave-in-place steel formwork, slab arris protection and a load transfer device in one product that initially simplifies the construction process of a concrete floor slab and protects the slab long term. Where a product is referred to throughout this document, it is the level of arris protection provided by the product that is being discussed.

A summary of the products under review in this document is found below; full product specification sheets can be found at http://www.permaban.com/downloads/technical-guides.

2.1 AlphaJoint®

There are several products within the AlphaJoint family. AlphaJoint® classic 4010 is currently recognised as being the industry leading slab arris protection system available and where AlphaJoint® is referred to throughout this document it is AlphaJoint® classic 4010 that is being discussed. A graphical representation of AlphaJoint is shown in Figure 2.1.

Commonly referred to as “joint armouring”, arris protection is provided by a 40mm x 10mm cold drawn, square edge bright mild steel bar that is discretely anchored to the concrete slab using shear studs. After casting the concrete slab, the only exposed components of AlphaJoint® are the top flats of each steel bar. This steel provides “armouring” to the brittle concrete edge behind it and can be seen in Figure 1.1.

Two steel sections are fastened together, back to back, using frangible connectors. One of the steel sections is welded to the sheet steel that functions as leave-in-place formwork. The frangible connectors fail as a result of the tensile force applied to them by the drying shrinkage of the concrete slab. This creates a gap, or joint opening, between each steel profile and as the drying shrinkage of the slab continues the width of the joint opening between the steel bars increases.

2.2 Permaban Eclipse®

The composition of Permaban Eclipse® is very different to AlphaJoint®. The sheet steel section used to provide leave-in-place formwork is folded and punched during fabrication so that it also provides continuous anchorage to the concrete slab. A triangular fillet of steel is welded to the underside of the sheet steel to provide “joint armouring”. A radiused “trafficked” edge as an alternative to the square edge found on AlphaJoint® is the result of the fabrication process. Permaban Eclipse® is shown in Figure 2.2.

2.3 Permaban Signature®

Unlike AlphaJoint® and Permaban Eclipse®, Permaban Signature® does not provide joint armouring. By
shaping the edge of the concrete slab, Permaban Signature® prevents the wheels of MHE from falling into the joint and impacting the concrete arris. Because there is no impact, there is no need to provide “joint armouring”. The shape of Permaban Signature® means that wheels cannot impact the concrete for joint opening widths of up to 40mm. An image of Permaban Signature® is shown in Figure 2.3.

![Figure 2.3 - Image of Permaban Signature®](image)

Like Permaban Eclipse®, Permaban Signature® is continuously anchored to the concrete slab. Two halves are fastened together using frangible connectors, which again fail as a result of the drying behaviour of the concrete slab, to reveal a semi-hexagonally shaped joint between two slabs.
3 Test Method

3.1 Expected test variables

To validate the performance of Permaban Eclipse® and Permaban Signature®, all testing had to be representative of the in-situ behaviour observed during the inspection work carried out on AlphaJoint® throughout the previous 10 years. This would allow accurate conclusions to be made as to the comparative performance of each new product, and their respective behaviour modes when trafficked long term by materials handling equipment.

Before consideration was made to the test method and test apparatus, the variables observed were first quantified as:

- Joint opening width
- Traffic frequency
- Traffic type
- Concrete durability and strength (functions of the age of concrete slab)
- Quality of AlphaJoint® installation
- Quality of finished slab

3.2 Specification of test apparatus

For the test to be representative of the in-situ performance of AlphaJoint®, the following specification was developed:

- Wheel type and size should be representative of logistics industry
- Speed should be variable
- Applied force should be variable
- Visible indicators of speed and force required
- Joint opening width should be variable
- Multiple arris protection systems should be tested simultaneously
- Concrete variability should be controlled

For purposes of this project it was agreed that, for comparative performance data to be obtained and to eliminate concrete properties as test variables, each test set should consist of sample slabs cast from the same batch of concrete.

Each test slab was also to contain a sample of AlphaJoint® to act as a control sample for the test, allowing comparisons to be made between each test sample and the in-situ performance of AlphaJoint® as observed over the previous 10 years. Repeatability between each test set and comparison back to in-situ product behaviour would validate the test approach used.

Based on the test apparatus specification, there were two possible apparatus delivery routes available. The first route was to develop test apparatus that travelled in a circular motion across the surface of a test slab, and travelling across arris protection systems installed perpendicular to the travel path to allow the behaviour of the protection system to be investigated when trafficked. The second route was to develop test apparatus that travelled linearly across the surface of a test slab, again travelling across arris protection systems installed perpendicular to the direction of travel.

The appraisal of each route is not covered in this document, however the former route was selected as the most appropriate delivery route as it was deemed easier to fabricate and more commercially viable.

3.3 Duration of test

Breakdown of the concrete slab behind AlphaJoint® can take many years. In order to validate the performance of Permaban Eclipse® and Permaban Signature®, an accelerated testing programme was required so that the level of arris protection provided by each product could be assessed in a short timeframe to allow product validation prior to launch in the marketplace. It was decided that a test should ideally last between one and two hours – too short a test would make differences between the failure modes of each product difficult to observe, and too long a test would make the project commercially unfeasible.

3.4 Test sample

The test samples were 1600mm x 1600mm x 160mm concrete slabs cast using fresh concrete supplied by a ready mix supplier. The concrete mix design and supplier remained constant for all test sets and consisted of:

- C32/40 compressive strength
- Max water: cement ratio of 0.55
- CEM1 cement
- Max aggregate size of 20mm
- S2 consistence class

Three arris protection systems were installed on a polar array of 120° within each concrete slab test sample.

All concrete slab test samples were densely powertrowelled and cured for a minimum of 28 days using polythene sheets prior to testing. Figure 3.2 shows a test sample during testing.

### 3.5 Test apparatus

A 3.2kW variable frequency drive motor with a 40:1 gearbox reduction rotated two steel wheels that were mounted on a 750mm long fixed axle. The circumference of the circle in which the wheels travelled was 2.36m. The test apparatus is shown in Figure 3.2.

The speed, torque and direction of travel of the test apparatus was controlled electronically through the I/O panel shown in Figure 3.1. Although variables the speed of the motor was kept constant throughout the project at 1700rpm and the direction of travel remained clockwise for all test sets.

The motor and wheels were housed in a reaction frame that was bolted to the test samples using three sprung legs. The compression applied to each spring remained a constant throughout each test set. The legs of the

![Figure 3.1 - I/O control panel](image1)

![Figure 3.2 - Test sample and test apparatus in laboratory](image2)
apparatus were bolted in a straight line away from each arris protection system.

The centreline of the axis of the wheels was positioned 30mm beneath the base plate of the apparatus legs. To initially calibrate the test apparatus, a series of 1.5mm gauge shims were used to remove the gap between the base plate of each leg and the concrete slab test sample, until the apparatus was raised sufficiently to allow free wheel rotation across the surface of the test sample. The power required to drive the wheels along the surface of the test slab was shown on the I/O control panel as 0.3kW. 0.3kW was then used as a baseline throughout the test.

After calibration, a 1.5mm shim was removed to apply downward pressure to the test sample through the reaction frame, increasing the power required to maintain 1700rpm to 0.8kW. The downward pressure applied from the apparatus was sufficient to abrade the surface of the concrete slab test sample by the depth of the shim removed. The test then continued until the power demand of the motor was reduced to 0.3kW, when a further shim was removed, returning the power demand to 0.8kW.

The test was concluded when sufficient spalling of the concrete behind AlphaJoint® had developed, such that in an operating logistics facility the performance of MHE would be severely impeded.
4  Test Results

The photographs contained in Section 4 show the average failure modes observed on the arris protection systems and surrounding concrete after testing. The results shown are representative of the results obtained from all test sets.

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<table>
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<tr>
<th>Duration of test</th>
<th>Observations</th>
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<td>After approx. 15 minutes of testing, or 0.5mm wear on surface of slab</td>
<td>Deformation of square edge of the steel on the approach edge of the approach slab.</td>
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<td>Spalling of the concrete behind leave edge of steel on the approach slab is greater than the depth of wear across the slab.</td>
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Figure 4.1 - Graphical reference for test sample features discussed in Table 1
| Minor deformation of the steel on the approach edge of the approach slab. | Figure 4.4 - Permaban Eclipse® testing - photograph 01 |
| Concrete wear has exposed Permaban Eclipse® slab anchor. |

| Minor spalling of the concrete behind leave edge of steel within the approach slab. | Figure 4.5 - Permaban Eclipse® testing - photograph 02 |
| Concrete wear has exposed Permaban Eclipse® slab anchor. Minor spalling behind leave edge of steel on the approach slab. |

| Deformation of steel to match the depth of wear of the concrete on approach and leave slabs. | Figure 4.6 - Permaban Signature® testing - photograph 01 |
| Breakdown of concrete around the steel profile matches the overall surface wear of the slab. |

| After approx. 90 minutes of testing, or 3mm wear on surface of slab | Figure 4.7 - AlphaJoint® testing - photograph 03 |
| Deformation of the steel along all edges. The steel profile along the approach edge of the leave slab shows signs of being deformed towards the direction of traffic, and a gap is forming between the steel and concrete. |
| Significant spalling of concrete along steel edges of both sides of joint. |
| A spalling depth of 7mm was recorded at the centre of the travel path on the approach slab. The depth of wear decreased as the wheels travelled away from the joint to match the overall surface wear of the slab. |
| Minor deformation of the steel along all edges. | Figure 4.8 - Permaban Eclipse® testing - photograph 03 |
| Minor spalling of concrete along steel edges on both sides of joint. | |
| An abrasion depth of 1mm was recorded at the centre of the travel path on approach slab. The depth of wear increased as the wheels travelled away from the joint to match the overall surface wear of the slab. | |
| Deformation of steel to match the depth of wear of the concrete on approach and leave slabs. | Figure 4.9 - Permaban Signature® testing - photograph 02 |
| Breakdown of concrete around the steel profile matches the overall surface wear of the slab. | |

Table 1- Results obtained from testing
5 Evaluation of results

5.1 AlphaJoint® results

Figure 4.2, Figure 4.3 and Figure 4.7 show the behaviour of AlphaJoint® and the surrounding concrete throughout the test process.

After only 15 minutes of testing, the concrete behind the steel “joint armouring” on the approach edge of the leave slab had spalled to a depth considerably greater than the surface wear of the slab. When the testing was complete, spalling of the concrete directly behind AlphaJoint® on the approach edge of the leave slab was significant.

This behaviour can be explained by considering a Newton’s Cradle – the kinetic energy from the first steel ball in the line of steel balls is transferred to the next ball through impact [2]. The ball ‘compresses’ under the force of impact, gaining potential energy that is then released as kinetic energy to the next ball when the ball returns to its original shape. The impact energy is transferred from one ball to the next. This principle applies to the steel “joint armouring” of AlphaJoint®; the kinetic energy of the steel wheel is transferred to the concrete slab through the steel “joint armouring”. The transfer of energy is dependent on the density of the materials involved, as well as the size and shape of the components. The transfer of impact energy though AlphaJoint® is shown in Figure 5.1.

The square edged steel section was deformed due to the impact of the steel wheels. This deformation of the steel “joint armouring” was the result of continuous impact by the small steel wheels of the test apparatus. For the steel to provide “joint armouring” the steel must be sufficiently resistant to impact deformation. The cross-sectional area of steel required to prevent deformation is dependent on the tensile strength and the malleability of the steel. It should be noted larger steel sections do not necessarily provide enhanced performance however larger steel sections often incur higher costs.

The AlphaJoint® arris protection steel is anchored to the concrete using discretely welded shear studs, spaced 250mm apart. It was observed that a gap was forming between the concrete and steel on the approach edge of the leave slab after abrasion of the surface had occurred. Impact to the arris protection steel away from an anchorage point allows deflection of the steel due to the impact force applied, however this is a function of the spacing of the shear studs and the level of exposure of the steel to impact. This issue did not present itself on the testing of Permaban Eclipse® due to the continuous anchorage offered by the punched steel profile.

5.2 Permaban Eclipse® results

Figure 4.4, Figure 4.5 and Figure 4.8 show how Permaban Eclipse® and the adjacent concrete performed during the during the test process.

The concrete anchors of Eclipse were exposed, as expected, during the abrasion of the concrete slab however the rate of exposure was the same as the rate of abrasive wear of the concrete slab. This demonstrates that the concrete anchors do not increase the likelihood of spalling and deterioration of the concrete.

The test was stopped after approximately 90 minutes, or 3mm of abrasive surface wear, as the AlphaJoint® installed in the same test sample was no longer deemed traffickable in an operating logistics environment. At this point approximately 1mm of abrasive wear of the concrete around Permaban

![Figure 5.1 - Energy transfer through AlphaJoint®](image-url)
Eclipse® was observed on both approach and leave slabs while only very minor spalling of the concrete was observed. The steel edge alongside the concrete was deformed to match the rate of abrasion of the concrete and the concrete anchors were further exposed as a result of the wear.

The impacted edges of Permaban Eclipse® deformed significantly less than that of Alphajoint®, due to the radiused edge of the steel profile. Permaban Eclipse® uses high tensile bar that is cold rolled to form the triangular fillet that provides armouring. Deformation of Permaban Signature® occurred only in the traffic path; i.e. deformation was local to the traffic zone only.

A lack of surface abrasion would mean no deformation to the steel profile of Permaban Signature® as no impact at the joint can occur.

### 5.4 Comparison of results against existing floor slabs

Figure 4.2 to Figure 4.6 show the deterioration of each arris protection system and the surrounding concrete after a wear depth of 0.5mm to the surface of the concrete slab test sample. The deterioration of the concrete observed behind Alphajoint® at this point is representative of that observed in working facilities. This level of spalling is sufficient to cause problems when trafficked by MHE. On average, this depth of wear was achieved after 15 minutes of testing. Using the information provided in Section 3.5 it is possible to calculate the speed at which the wheels travelled across each concrete slab test sample as:

\[
2.36m \times \left( \frac{1700 \text{rpm}}{40} \right) \times 60\text{min} = 6018\text{m/hr or 6km/h}
\]

Typically electronic pallet trucks, order pickers and very narrow aisle (VNA) equipment operate between 6km/h and 12km/h. The speed at which the wheels of the test apparatus travelled is therefore representative of that within the logistics industry.

Using further information provided in Section 3.5, it is possible to calculate the approximate number of times each arris protection system was trafficked in the 15 minute period as:

\[
\left( \frac{6018}{2.36} \right) = 637.5 \text{times trafficked by one wheel}
\]

\[
637.5 \times 2 \text{ wheels} = 1275 \text{ times trafficked}
\]

The spalling observed behind Alphajoint® during this project is comparable to the spalling observed during inspection visits to facilities in which Alphajoint® has been installed. It can be particularly likened to the deterioration of floor slab joint arrises found in facilities subject to very aggressive directional traffic.
such as a logistics facility containing very narrow aisles and associated materials handling equipment. The number of passes in 15 minutes is representative of the VNA industry – the nature of these facilities means that the same area of floor and the joints contained within it are trafficked repeatedly and continuously.

The aggressive surface abrasion of the concrete slab test samples experienced towards the end of each test (3mm depth of wear) is not necessarily representative of typical existing floor slabs. However, the surface abrasion exposes the steel “joint armouring” to impact, allowing greater damage to be caused by the wheels of the test apparatus. This helped to accelerate the testing process and identify possible long term issues that could present in situations where Permaban Eclipse® and Permaban Signature® are heavily trafficked, while providing performance comparisons against AlphaJoint® in an aggressive environment.
6  Recommendations for product use within a logistics warehouse

6.1 AlphaJoint®

AlphaJoint has performed satisfactorily for many over the last 10 years. However, the demands placed on the concrete floor slab in a modern logistics facility are ever increasing.

It is the recommendation that AlphaJoint® is no longer installed in demanding logistics environments, so that the future operational efficiency of a facility is not threatened and the performance of MHE is not impeded.

6.2 Permaban Eclipse®

Permaban Eclipse® offers superior arris protection performance to AlphaJoint®. It is the recommendation of this document that Permaban Eclipse® be used to provide arris protection throughout a logistics building.

The use of Permaban Eclipse® will protect the slab from deterioration; however MHE trafficking across the joint still has the potential to be damaged due to the nature of the product.

6.3 Permaban Signature®

This project has demonstrated that Permaban Signature® is not subject to impact from MHE as they traffic a concrete floor slab joint. This means that no deterioration of the concrete can occur, and also means that no damage to the MHE will result from trafficking across the joint.

It is the recommendation that Permaban Signature® is used in areas within a logistics facility where high traffic levels are expected, particularly directional traffic that travels perpendicular to the joint, such as VNA areas, internal thresholds and dock loading areas of a building. The increased initial building cost of installing Permaban Signature® over Permaban Eclipse® is small when a holistic view is taken and the long term cost of maintenance to the floor and MHE is considered.

The nature of a logistics industry facility means that the occupier of a building may change regularly. Different users have different operating requirements. Installing Permaban Signature® at all formed construction joints in a logistics facility will yield the maximum level of flexibility and long term efficiency for both the occupier and the owner of the logistics facility.

Permaban Signature® prevents impact by MHE for joint opening widths of up to 40mm. This makes Permaban Signature® the most appropriate choice when larger joint openings are expected, such as cold store facilities.

The nature of Permaban Signature® also means that it is suitable for providing slab arris protection in facilities where it is possible that the surface of the slab be aggressively abraded, such as waste transfer stations.
7 Recommendations for future work

Test apparatus in which the wheels travel linearly across the surface of the slab would more closely represent the behaviour of a VNA truck. A reciprocating drive has been developed at Aston University [3]. The results obtained from this project should be compared to those obtained from the work completed at Aston University. This would validate each approach to testing and would deepen the understanding of arris protection systems further.
8 References


