Microplastic Emission from Road Markings in Germany and Austria

Introduction

Synthetic polymers, so-called plastics are omnipresent in daily life thanks to excellent performance and longterm durability. For instance, plastics binders in road marking materials must provide good adhesion to the road surface and a solid anchor for pigments and glass beads that reflect the car headlight at night. Durability of the binder is key to provide long lasting visibility and traffic safety. However, even the most durable road marking material will be abraded to a certain extend over time when exposed to traffic wear and to elements.

Microplastics are tiny fragments of solid, non-water soluble synthetic polymers that are less than 5 mm in size and resist (bio)degradation. When entering the sea these objects are hazardous to the aquatic life. The Plastics Strategy of the European Commission adopts a step by step approach to reduce the emissions of microplastics from all sources: Firstly, the intentionally added (primary) microplastics in products, such as toothpaste, creams, detergents. Secondly, microplastics that are generated unintentionally during the life-cycle of products, and finally, plastic waste entering the sea and ultimately becoming microplastics because of fragmentation, if the waste is not removed.

At the request of European commission in January 2019, ECHA proposed a wide-ranging restriction on intentional uses of microplastics (primary microplastics) in products placed on the EU/EEA market to avoid or reduce environmental pollution. Registry of restriction intentions until outcome - ECHA (europa.eu). This restriction is up for discussion at the REACH committee with the possibility of a vote in December 2023. The EU commission has launched a public consultation on how to reduce the amount of unintentionally released microplastics (secondary microplastic) into the environment best on 22 February 2023 Microplastics public consultation (europa.eu). It will focus on labelling, standardization, certification and regulatory measures for the main sources of these plastics Microplastics pollution – measures to reduce its impact on the environment (europa.eu). EU JRC has reviewed road marking technologies in the following manner: Technical Report for Paints Varnishes and Road Markings (FINAL).pdf

In accordance with EN 1436 road markings form a part of the means for horizontal signalization. They include longitudinal markings, arrows, transverse markings, text and symbols on the surface of the road and can be 'provided by the application of paint, thermoplastic materials or cold hardening materials, preformed lines and symbols or by other means'. Road markings can be applied with or without the addition of glass beads. The majority of road markings are white or yellow. Glass beads are tiny spherical glass balls used to achieve the retroreflection of the marking when the road marking is illuminated by vehicle headlamps. This retroreflection can also be improved, particularly for wet or rainy conditions, by special properties produced e. g. by the texture of the surface (in structured markings) or addition of large glass beads. In addition, textured road marking surfaces may cause acoustic or vibrational effects when rolled over by wheels of passing vehicles. Glass beads are dropped on top of a freshly applied road marking and/or can be mixed in with marking before it is applied. Glass beads can be treated with adhesion and flotation coating to promote the good and correct embedment into the road marking product or the combination of the two, to endow the road marking of retroreflection properties during lifetime. There are various material technologies with different solidification methods used in road marking systems. According to information collected from industry among them there are:

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- Water-borne paints – sprayed on the road surface, dry by coalescence and water evaporation, form a thin layer
- Solvent-borne paints – sprayed on the road surface, dry physically by evaporation of solvent, form a thin layer
- Thermoplastics – applied in the molten state at about 200°C, either sprayed on (thin layer) or casted on as a melt (thick layer), solidifying by cooling
- Reactive road marking systems (the so-called 2-component cold plastics) – mixed with a second hardener component. They are applied at ambient temperatures (are sprayed on (thin layer) or casted on (thick layer)) and solidify by chemical curing into an inert duroplastic polymer

Besides these major road marking systems other technologies such as for instance preformed tapes are occasionally used.

The importance of glass beads for the functionality of road markings as far as nighttime visibility (retroreflectivity) is concerned as well as the importance of longterm durability of road marking systems was highlighted. However, microplastic emissions caused by road markings have only recently been taken into account.

Microplastic emissions from road markings

Actual studies on microplastic generation from road markings are widely based on the simplifying assumption that up to 100 % road marking material applied in a year is required to replace the material that has been abraded the year before. Thus road markings are ranking among the top 10 sources for microplastic emissions in various studies (see Eunomia Investigating How to Stop Microplastics from Products Escaping into the Aquatic Environment - Eunomia and references therein).

A more recent study by Frauenhofer Intitute concludes that for Germany annually about 91 grams per capita (7.500 tons) of microplastic is originating from road marking abrasion Kunststoffe in der Umwelt: Mikro- und Makroplastik (fraunhofer.de). In comparison to abrasion from tires, which is the biggest source of microplastics with 1228.5 g/(cap a) according to this study, abrasion from road markings generates 13.5 times less microplastic and is ranking no. 9 among the top 10 sources for secondary microplastics in Germany (see figure 1).

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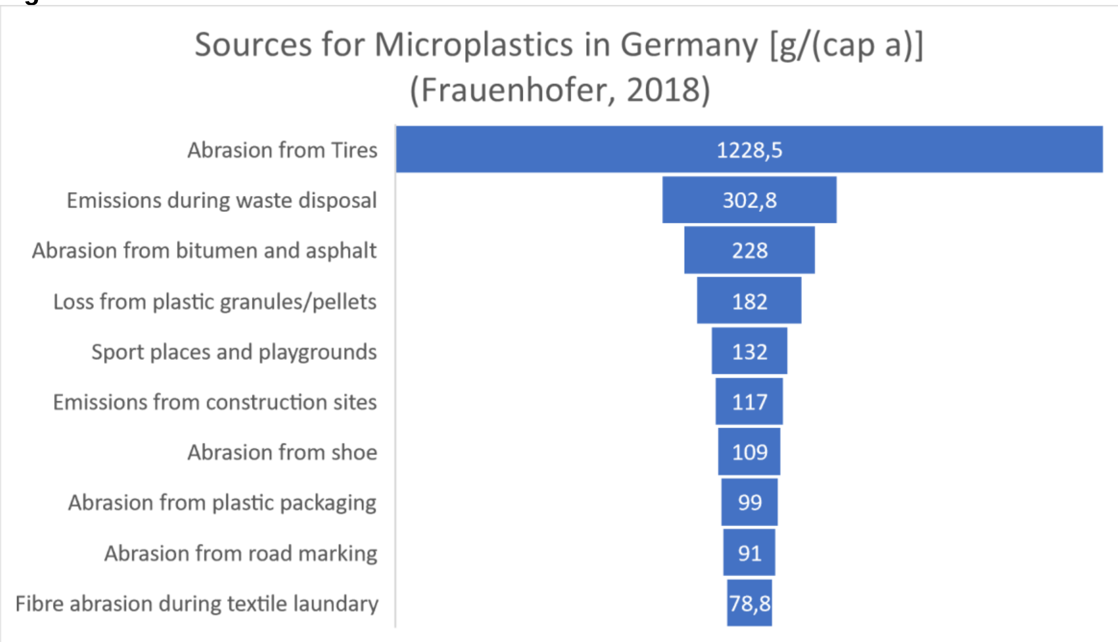
Figure 1



Given the fact that about 30.000 tons of road marking materials are typically applied in Germany annually [DSGS 2015] this suggests an abrasion level of 25 % of all material applied annually.

Up to now no solid evidence is available that microplastic from road marking is present in the environment in significant amounts compared to various other species. Analysis of polymer traces in rinse-off water collected at road site in Berlin city revealed that SBR polymer associated with microplastic from tires was omnipresent in all analyzed samples in significant amount. In contrary to that PMMA was detected only occasionally in some of the samples in marginal amounts *[Matzinger et al., 2018. Verbundprojekt OEMP: Optimierte Materialen und Verfahren zur Entfernung von Mikroplastik aus dem Wasserkreislauf. Schlussbericht Förderkennzeichen 03XP0045C. Kompetenzzentrum Wasser Berlin GmbH: Berlin, Germany]*. However, apart from road markings there are many other potential sources for PMMA in urban areas, such as abrasion from façade paints, for instance.

Taking practical experience into account a critical review on literature on microplastic emission from road markings concludes that present studies overestimate the microplastic generation drastically since they do not address the renewal frequency of road markings and its association with the key parameter of road markings – retroreflectivity. This parameter, achieved because of a layer of glass beads on the road markings surface, fails before the plastic-bearing layer could be abraded. https://www.sciencedirect.com/science/article/pii/S1361920921004181.

This report provides practical analysis on road as well as laboratory assessments of abrasion of actual road marking systems. The analysis of worn road marking installations on highly trafficked cross walks in Poland, Austria and Croatia reveled an abrasion of 0.4 % to 7 % depending on the actual road marking system and on the actual traffic volume as well as on the winter service conditions, namely the exposure to snowplow. Even in the case of cold plastic that is heavily worn by traffic as well as by snowplow to an extend that the lines are hardly visible at nighttime anymore (retroreflectivity as low as 23 mcd/sqm/lx)

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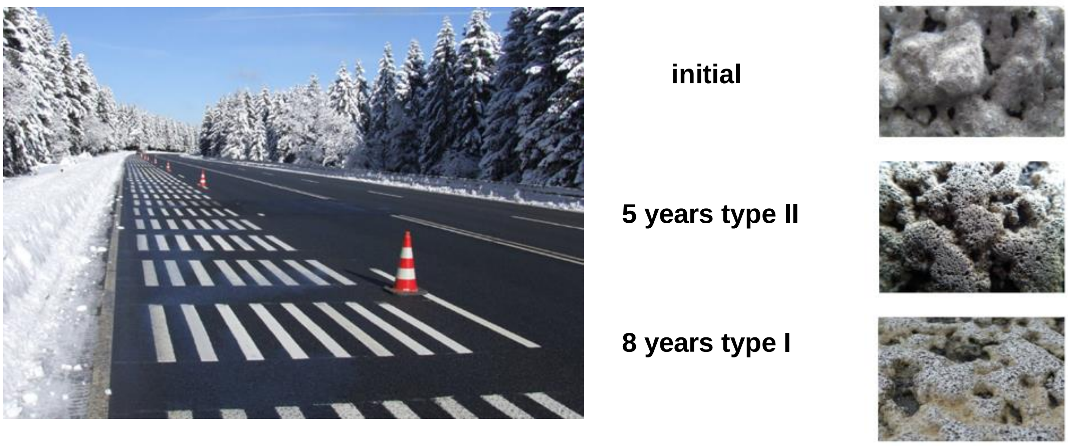
the majority of the material (93 % and more) was present. Only the analysis of a Swedish installation revealed a higher level of abrasion, namely 22.1 % of the initially applied thermoplastic material, which is attributed to the fact that road markings in the scandic area are exposed to extreme abrasion by studded tires. Analysis of the paint installation at a moderately trafficked pedestrian crossing in Croatia demonstrated the presence of several layers of paint and glass beads, confirming that the road markings were renewed before abrasion of the plastic material actually took place. In addition to that Burghardt et al. demonstrated by rotary abrasion tests according to ASTM D 4060 that abrasion resistance of paint-type road marking systems is greatly depending on the presence of glass beads on the paint surface.

The findings of Burghardt et al. for Austria, Poland and Croatia are in line with German road marking practice. High presence of cold plastic and thermoplastic materials even after 8 years of service under harsh abrasion conditions has been demonstrated on the German test field at federal road B4 at Torfhaus (see picture 1). The location in the Harz mountains offers the possibility to monitor performance of road marking systems under both traffic of 8000 vehicles per day on average and snowplow abrasion. While paints cannot withstand such abrasion conditions more durable systems, such as cold plastic or tapes or thermoplastic are clearly visible for many years. Recent analysis of abrasion of 91 different road marking samples present at this test field by DSGS revealed that some of these durable materials withstand such harsh abrasion and remain present for more than a decade (see appendix).

Picture 1 Cold plastic agglomerate road marking after 8 years in service under traffic and snowplow operation at German test field at federal road B4 at Torfhaus (sample 80; applied 30/08/2007)



Picture and data sources: DSGS

Proof for abrasion resistance of certain road marking systems can be found on urban Austrian roads. Some yellow cold plastic lines are still occasionally present on busy roads although application of yellow permanent markings had been ceased in 1994 after a revision of Austrian guidelines for road marking application (ZTVÖ). Picture 2 shows an old yellow cold plastic line in the state of Kärnten, which is routinely re-coated with white road marking paint and fresh drop-on glass beads to restore nighttime visibility. Obviously, the paint refreshments do not withstand the traffic and snowplow abrasion in such urban area over winter, but the cold plastic system has been withstanding the wear to a large extend for more than 30 years now.

Picture 2 Old yellow cold plastic road markings at an urban junction in Kärnten/Austria installed more than 30 years ago

Source: Rembrandtin Coatings GmbH

Long term monitoring of road marking installations without any interference of re-coating is done at Siemensstraße at Vienna. Here cold plastic road markings are still remaining after more than 20 years of exposure to an average daily traffic load of about 16000 vehicles (see picture 3). This suggest the average annual material loss is less than 4 % of the initially applied cold plastic material at this busy urban road.

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Picture 3 Old road markings at Siemensstraße in Vienna/Austria exposed to an average daily traffic 16000 vehicles

Assessment of microplastic emission from road makings based on German road marking practice

Application of road marking systems in Germany is done according to the guidelines of ZTV M 13 *[Zusätzliche Technische Vertragsbedingungen und Richtlinien für Markierungen auf Straßen, FGSV Verlag GmbH, Köln, 2013]*. Hence only certified materials are applied with a dosage per sqm as specified by the corresponding approval test certificate. ZTV M 13 provides criteria for the selection of road markings systems depending on traffic volume and specifies minimum requirements on performance of road markings with enhanced nighttime visibility in wet condition (type II markings) or with standard nighttime visibility (type I markings). Renewal of road markings is recommended when nighttime visibility of a marking in use falls below 80 % of the minimum value of performance classes R2, respectively RW1 according to EN 1436.

Given this regulatory background and German road marking practice typical application scenarios for the various road marking material technologies in representative system compositions are compiled in table 1. For instance, road marking paint systems are typically applied as type I systems only on secondary roads with rather low traffic volume of less than 5000 vehicles per day, while thermoplastic or cold plastic is applied as type II markings on highly trafficked roads with more than 10000 vehicles per day on average. Microplastic generation is calculated individually for each system depending on the level of erosion of each system type when retroreflection falls below 80 % of the minimum requirement. This is when the functional durability ends, namely the time the system is used until visibility falls below this threshold. Assessment of both erosion factor and functional durability for the individual systems at the corresponding traffic load are based on practical experience at test field B4 (see Appendix Table A1) with rather demanding abrasion conditions as well as on empirical observations on other roads in Germany. Loss of optional premix glass bead components in the materials are not considered as microplastic, due to the purely in-organic nature of abrasion.

Table 1 Assessment of microplastic emission due to abrasion of road markings in Germany

Products	Range of application depending on averange daily traffic volume (vehicles per day)	Dry density	Solid content (%)	Dosage (g/m²)	% Premix beads	Errosion Factor according to practical experience on roads in Germany	Functionnal Durability at 80% of minimum retro-reflectivity in use phase required by ZTV-M13 Section 4.13 (Years)	Annual quantity produced/applied (2015; DSGS) (MT)	Annual material loss (w/o premix) (g/m²)	Total amount of material loss per annum (MT)
Thermoplastic Flat Typ II	>10000	2	100	6000	30	0,5	8	7500	263	328
Cold Plastic Flat Type II	>10000	1,93	99	5790	25	0,15	8	5000	81	70
Thermoplastic Agglo Typ II	>10000	2,1	100	3700	30	0,7	8	1500	227	92
Cold Plastic Agglo Type II	>10000	1,93	99	2800	25	0,25	9	5000	58	103
TP Spray Type II	>10000	1,92	100	2300	20	0,7	5	1000	258	112
SB Type I	< 5000	1,57	75	630	0	0,5	4	5000	59	469
WB Type I	< 5000	1,6	75	640	0	0,5	4	1000	60	94
CSP Type II	5000 - 15000	1,58	98	950	0	0,25	5	3000	47	147
CSP Type I	5000 - 15000	1,58	98	640	0	0,25	5	1000	31	49
							Total	**30000**		**1463**

Considering the annually applied amount of major road marking materials in Germany (30000 tons) an annual material loss of 1463 tons, respectively 4.9 % is calculated. Biggest single contribution to the microplastic emission according to this assessment originates from paint systems that account for more than one third of the microplastic emissions although they represent only one fifth of the annually applied material volume.

This calculation does not consider road marking materials that are grinded off before functional durability is exhausted in preparation of new marking applications or due to pavement renewal. Such grinded-off material is typically reused in the foundation of new pavements or in the new pavement itself and therefore physically bound. This decreases the amount of the actual material loss by approximately 5 – 15 %.

Thus, the annual microplastic emission in Germany can be estimated in conservative manner to be about 4.4 % of the annually applied amount of road marking materials.

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Conclusions / Recommendations

In light of this data it can be concluded that the study by Frauenhofer is overestimating the microplastic emission from road markings by far. The road marking practice suggests not more than 4.4 % annual microplastic emission based on the totally applied marking material per annum. This assessment corresponds with the minor abondance of PMMA traces in rinse-off water collected at urban city roads in Berlin.

This assessment for microplastic emission from road markings in Germany is in accordance with evaluations of other countries with comparable abrasion conditions, such as Austria, Poland and Croatia, where typically less than 5 % abrasion is observed.

Practical experience as well as analytical data proofs that sufficient presence of drop-on glass beads on the marking surface prevents abrasion of road marking material efficiently. Only when this protective glass bead layer is worn off microplastic emission from material sets in. Particularly less abrasion resistant paint systems require this protective glass bead layer to remain present on the road. At the same time the nighttime visibility of the markings depends on the presence of sufficient glass beads on the surface. Thus, frequent renovation of the markings with fresh drop-on beads ensures both high safety functionality (visibility) as well as low microplastic emission.

Road marking is without any doubt an essential application since markings are indispensable for road safety and cannot be substituted by other means. Due to the extreme wear conditions on road site and full exposure to the elements durable materials of high performance are required. Thus, there are currently no material alternatives available to substitute the approved and tested technologies. At the same time there is no option to restrict the use of the material consumption without drastically compromising the safety features and especially the durability of the marking systems.

State-of-the-art execution of manufacturing and application of the materials in the approved composition and system design should be enforced to achieve a high level of performance and durability that ensures minimum material loss during installation and usage on the road. This requires well trained skilled personal.

Options to reduce microplastic emission from road markings in Germany are:

- Usage of more durable marking materials at elevated traffic level
- More frequent renewal of road marking systems to maintain a protective layer of drop-on glass beads to prevent exposure of the material to tires.
- Instruction of proper handling and application of materials to ensure state-off-the-art execution
- Enforcement of installation of materials according to the approved composition and system design.

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Appendix

Average wear of different road marking systems on the test field in the Harz Mountains, Germany analyzed by DSGS in September 2022 [Dr. Claudia Drewes, DSGS e. V. 2022 https://dsgs.de/data/CMM_Contents/files/ForsChung-Mitteilungen/Average-wear-of-different-road-marking-systems-2022-10-17.pdf]

DSGS opened this road trial on the federal route B4 in the Harz Mountains near the village of Torfhaus in Germany in September 2006. The average traffic load is about 8.000 vehicles per day. Each sample on the test field consisted of 8 lengthwise stripes according to EN 1824 (Road trials), each stripe was 2 metres long and 15 centimetres wide, the distance between two stripes was 20 centimetres and the gap between two samples was 1 metre. The objective of this test field was to learn which marking materials were suitable for the use in regions where snow plowing and other kinds of winter service takes place. This is why there are commonly used road materials as well as newly developed materials present on the test field. Retroreflectivity and other performance criteria of the individual samples are annually monitored by DSGS. There were 91 samples present on the test field when the annual inspection took place in week 35, 2022. This time additionally the abrasion of the individual samples was evaluated. The following diagram shows the average wear of the corresponding class of road marking material [%] versus the duration of traffic exposure [years] after application on the road, whereby the samples were classified into the following marking systems:

9 x CP flat line
12 x CP agglo irreg.
5 x CP agglo irreg. + old agglo
9 x CP agglo reg.
2 x CP agglo reg. (+underline)
11 x CSP
11 x TP flat line type **I**

9 x TP flat line type **II**
3 x TP flat line preformed
2 x TP flat line/inlay
2 x TP agglo reg.
7 x TSP
5 x tape profiled
4 x tape profiled (yellow)

Abbreviations:
CP = cold plastic
CSP = cold spray plastic
TP = thermoplastic
TSP = thermo spray plastic
agglo = agglomerates
reg. = regular
irreg. = irregular

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Figure A1 The average wear of various road marking systems versus duration of exposure to traffic and snow plowing at German test field B4. The functional lifetime with respect to mainly nighttime-retroreflectivity of these systems is typically much shorter.

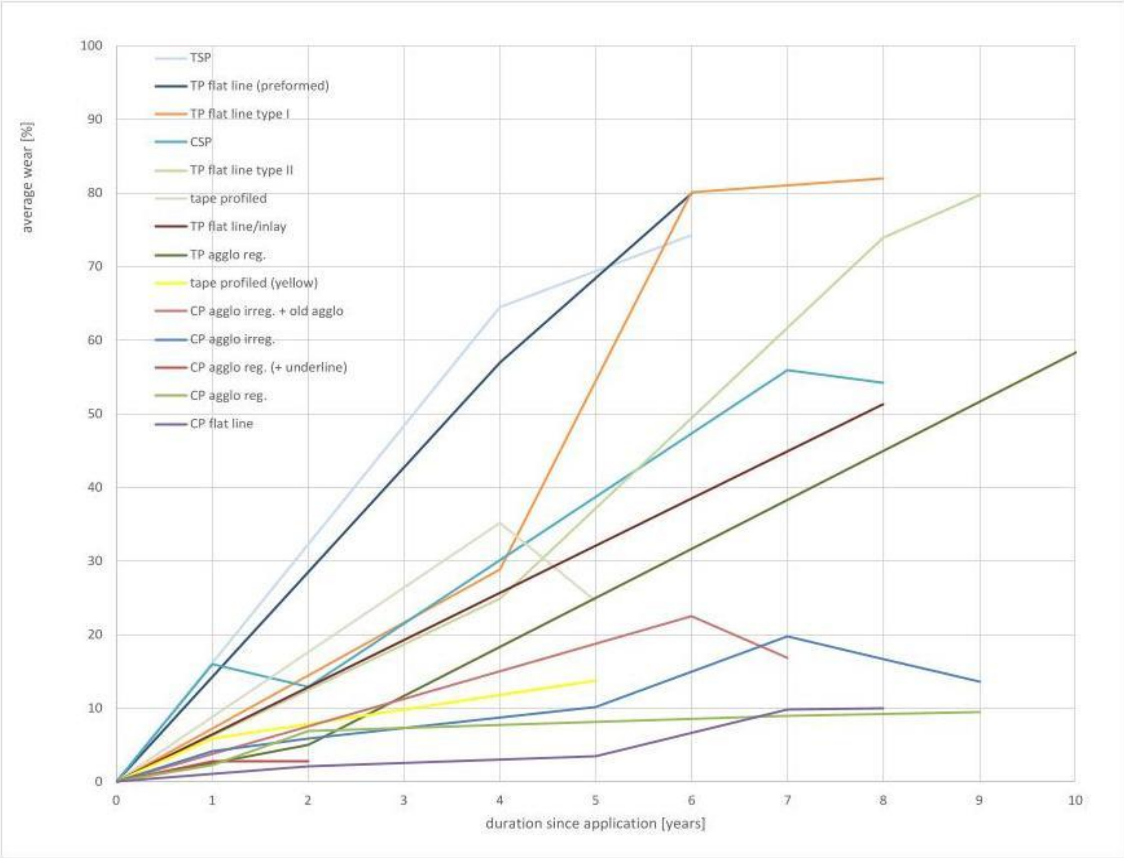

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Table A1 The average wear per year [%] of various road marking systems present in 2022 at German test field at B4 in the Harz mountains as well as the average duration [years] until 50 % of the corresponding materials would have worn off under these traffic and winter service conditions. The functional lifetime with respect to mainly nighttime-retroreflectivity of these systems is typically much shorter.

Road marking system class	**Average annual wear of the system [%]**	**Average annual duration until 50% material abrasion [years]**
Thermoplastic sprayed	14.2	3.5
Thermoplastic flat line preformed	13.8	3.6
Thermoplastic flat line type I	10.3	4.9
Cold spray plastic	9.3	5.4
Thermoplastic flat line type II	8.1	6.2
Profiled tape	6.9	7.3
Thermoplastic flat line inlayed	6.4	7.8
Thermoplastic regular agglomerates	4.4	11.5
Profiled tape (yellow)	4.3	11.6
Cold plastic irregular agglomerates applied on old cold plastic agglomerates	3.1	16.2
Cold plastic irregular agglomerates	2.6	19.3
Cold plastic irregular agglomerates with underline	2.1	23.4
Cold plastic regular agglomerates	2.0	24.7
Cold plastic flat	1.1	45.1

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