STEEL- AND POLYMER-FIBRE-CONCRETE IN GERMANY

WHITE PAPER

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CONTENTS

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1. EXECUTIVE SUMMARY

- In Germany, fibre reinforced concrete is mainly made of steel fibres and, to a lesser extent, polymer fibres.
- Steel fibre reinforced concrete is a regulated construction material in Germany and can therefore be designed and used.
- Polymer fibres in accordance with DIN EN 14889-2 can be placed on the market with a CE mark, but their use is only permitted with a national technical approval (abZ) if requirements in accordance to building law exist and/or concrete in accordance with DIN EN 206-1 in conjunction with DIN 1045-2 is used.
- In Germany, there is no document introduced under building law that regulates the design of polymer fibre-reinforced concrete if the fibres are to be applied structurally. Therefore, in addition to an abZ for the polymer fibre, an abZ or a project-related approval (ZiE) must be available.
- In Germany, polymer fibres may not be used as structurally effective without further proof, but may only be used in structural components/structures with a low hazard potential (without requirements under building law and/or water law), without having to observe further boundary conditions, if no concrete in accordance with DIN EN 206-1 in conjunction with DIN 1045-2 is used. In this case, however, the fibres are not to be applied structurally. The residual flexural tensile strength (performance class) may be applied.

2.1 Introduction

In Germany, steel fibres are predominantly used in fibre-reinforced concrete. In addition to steel fibres, polymer fibres are also used, which are also referred to as synthetic fibres. To a lesser extent, other fibres consisting of, for example, alkali-resistant (AR) glass, basalt or carbon are also used.
This white paper focuses on the application of steel and polymer fibres in Germany.

The following two questions are essential for the targeted use of the two fibre types in Germany:

1. What are the technical requirements for the properties?
2. What are the formal requirements for the fibre to be allowed to be used in the respective area of application?

In the following sections, the normative fundamentals are first summarized and then the classification in the respective areas of application is presented.

2.2 Normative basics of fibre-reinforced concrete

For the use of steel fibre reinforced concrete, various regulations have to be observed in Germany.
The **design** of (fibre) concrete is carried out according to Eurocode 2 (EC2) "Design of concrete structures – Part 1-1: General design rules and rules for building construction", editions: DIN EN 1992-1-1:2011-01 [1] and DIN EN 1992-1-1/NA:2013-04 (NA) [2].

In Germany, the **building material "concrete"** is regulated by DIN EN 206-1 "Concrete – Part 1: Specification, performance, production and conformity", edition: 2001-07 [3] in conjunction with DIN 1045-2 "Concrete, reinforced and prestressed concrete structures" – Part 2: Concrete – Specification, properties, production and conformity – Application rules for DIN EN 206-1, edition: 2008-08 [4]. DIN EN 206-1 [3] has been withdrawn, but is relevant for the building authorities in Germany, since the currently valid DIN 1045-2 [4] refers to DIN EN 206-1 and DIN EN 206 has not yet been introduced by the building authorities (cf. current Model Administrative Provisions Technical Building Rules (MVV TB), edition 2021/1 [5].

The **specifications** for the design of concrete load-bearing structures can be found in DIN EN 13670, edition: 2011-03 [6].
The following two **product standards** are currently valid for the two fibre types **"steel and polymer fibres"**:

DIN EN 14889-1 "Fibres for concrete - Part 1: Steel fibres – Definitions, specifications and conformity", edition: 2006-11 [7].

DIN EN 14889-2 "Fibres for concrete - Part 2: Polymer fibres – Definitions, specifications and conformity", edition: 2006-11 [8].

For the use of **steel fibres as concrete admixtures**, the guideline of the German Committee for Reinforced Concrete (DAfStb) "Steel fibre concrete supplements and amendments to DIN EN 1992-1-1 in conjunction with DIN EN 1992-1-1/NA, DIN EN 206-1 in conjunction with DIN 1045-2 and DIN EN 13670 in conjunction with DIN 1045-3", edition: 2021:06 [9] applies in Germany. For **polymer fibres**, there is currently no corresponding set of rules.
The design standard (EC2 [1, 2]) does not contain any information on the use of fibres, while DIN EN 206-1 [3] states the following with regard to fibres:

> Additional or deviating requirements may be given in other parts of this standard or in other special European standards, e.g. for the use of other building materials (e.g. fibres) or starting materials not included in 5.1.

Section 5.7.1 of DIN 1045-2 [4] specifies the application of fibre concrete in Germany for both steel and polymer fibres:

> **Loose steel fibres** in accordance with **DIN EN 14889-1**, whose conformity with the system of certificate of **conformity "1"** has been proven, are considered suitable.
> **Steel fibres according to DIN EN 14889-1** that have been **glued or added in a metering package** are also considered suitable if their usability with regard to the delivery form has been proven by a **national technical approval (abZ)**.
> **Polymer fibres** according to DIN EN 14889-2 are only suitable if their usability has been proven by a **national technical approval**.

> **Loose steel fibres in accordance with DIN EN 14889-1, whose conformity with the system of certificate of conformity "1" has been proven, are considered suitable.**

In summary, the use of steel fibres in concrete is regulated by DIN EN 206-1 [3] in conjunction with DIN 1045-2 [4] and the DAfStb guideline "Steel fibre reinforced concrete" [9]. For polymer fibres, there is no document introduced by the building authorities as for steel fibre reinforced concrete (DAfStb guideline steel fibre reinforced concrete [9]). The usability must be proven by an abZ.
A design for polymer fibres according to EC2 as a structurally effective fibre is therefore not possible, since only unreinforced design is allowed!

The client must be informed if other codes are used (e.g. TR034 [19]). In Germany, these are not among the generally accepted rules of technology.

2.3 Special features of polymer fibres (synthetic fibres)

According to the product standard DIN EN 14889-2 [8], polymer fibres are to be classified by the manufacturer according to their physical form as follows.

Class Ia:	Micro fibres: < 0.30 mm in diameter; Mono-filamented;
Class Ib:	Micro fibres: < 0.30 mm in diameter; Fibrillated;
Class II:	Macro fibres: > 0.30 mm in diameter.

DIN EN 14889-2 for polymer fibres differentiates according to intended use with regard to the system of attestation of conformity

- **Structural** uses: System "1"
  (Third-party inspection (incl. material tests) & factory production control)
- **Other** uses: System "3"
  (factory production control)

For polymer fibres monitored according to system 1, the addition of the fibres affects the load-bearing capacity. In the case of polymer fibres, load-bearing capacity is defined not only in terms of structurally effectiveness but also in terms of "fire protection" and "shrinkage cracking".

For fire protection, micro fibres are used. For shrinkage cracking, there are both approved micro and macro fibres. For the structurally effectiveness application, macro fibres are used. Table 1 in Section 3.5 shows an overview of the application fields for both steel and polymer fibres.

Only polymer fibres whose effectiveness for concrete as a structurally effective fibre has been proven may be used. For the applications "shrinkage cracking" or "fire protection effect", the effectiveness must also be proven for the application.
The current abZ on structurally effective polymer fibres states the following:

For concrete, the effectiveness of the PP-fibre as a structurally effective fibre in **building products**, for the use of which, however, a **separate national technical approval** or **project-related approval is required**, has been proven.

Construction products made of the concrete, in which the strength properties of the fibres are taken into account structurally, **require a separate national technical approval or project-related approval**.
The contribution of the polymer fibre to the **load-bearing resistance** of a fibre-reinforced concrete component is dependent on temperature and time and must be demonstrated by a **national technical approval** or a **project-related approval**.

For the use of polymer fibres as structurally effective reinforcement, a separate proof for the specific application as fibre-reinforced concrete is always necessary [10].

"For the use of polymer fibres as structurally effective reinforcement, a separate proof for the specific application as fibre-reinforced concrete is always necessary."

In Germany, DIN EN 206-1 in conjunction with DIN 1045-2 does not specify any concrete minimum requirements for fibres.

Polymer fibres in accordance with DIN EN 14889-2 can be marketed with a CE mark, but their use is only permitted with a national technical approval (abZ). If requirements in accordance to building law exist and/or concrete in accordance with DIN EN 206-1 in conjunction with DIN 1045-2 is used.

3. APPLICATION OF STEEL AND POLYMER FIBRES

3.1 General

The applications of steel and especially polymer fibres depend on the stresses to which the structure or component is subjected. The following Fig. 1 shows the dependence of the effective flexural tensile strength on the dosage for both steel and polymer fibres (here: macrosynthetic fibres). The investigations were carried out in accordance with SIA 162/6 [16].

> **An increase in the effective flexural tensile strength of the polymer fibres compared to the steel fibres cannot be achieved by increasing the fibre content.**

While effective flexural tensile strengths f_{ctf} in the range of approx. 0.3 to 1.1 N/mm² are achieved with the investigated polymer fibres with contents of approx. 1 to approx. 11 kg/m³, with the investigated steel fibres effective flexural tensile strengths of approx. 0.4 to approx. 2.3 N/mm² are present. With a dosage of approx. 10 kg/m³ of the polymer fibres, the same performance is achieved as with approx. 25 kg/m³ of steel fibres. According to the explanations in [15], an increase in the effective flexural tensile strength of the polymer fibres compared to the steel fibres cannot be achieved by increasing the fibre content.

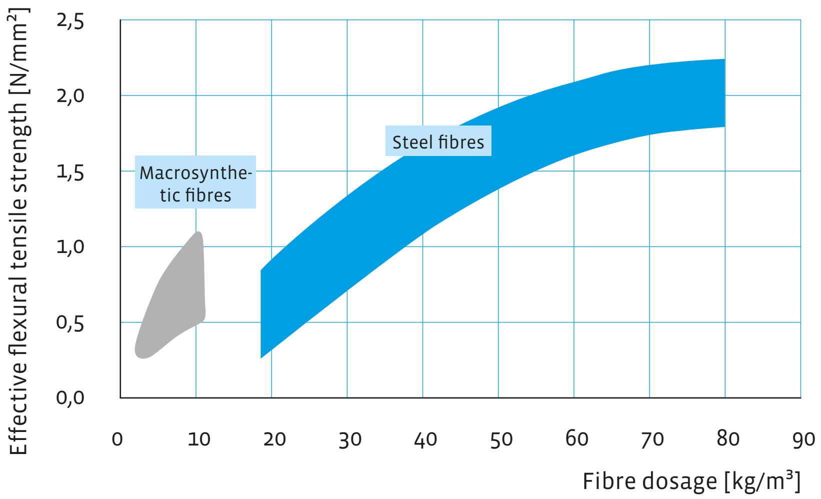

Fig. 1: Effective flexural tensile strength f_{ctf} according to SIA 162/6 of different fibre types as a function of dosage [15], date of retrieval: 11.07.2022

3.2 Steel fibre reinforced concrete application

When steel fibre reinforced concrete is used for components and structures in Germany, an evaluation in the form of a classification must first be carried out. As can be seen from Fig. 2, a classification of the component or structure can be with low hazard potential, with requirements to building law or with requirements to water law .

Application of steel fibre reinforced concrete for components and structures

Classification	With low hazard potential (without building law and/or water law requirements)		With requirements in accordance to building law	With requirements in accordance to water law
Regulations	No load-bearing components according to EC2 1)	Unreinforced structural components according to EC2 1) (structural reinforcement only)	Reinforced components according to EC2 1) & DAfStb guideline Steel fibre reinforced concrete	DAfStb guideline on concrete construction when handling water-endangering substances
Approach	Use of residual flexural tensile strength (performance class)	Steel fibres used for serviceability limit state design	Verification of ultimate and serviceability limit states	Minimum reinforcement or sealing layer with limitation of the crack width
Examples	• Industrial floors • Traffic areas • Basement floors • Retaining walls up to 1.0 m terrain step • Shafts up to 0.9 m depth	• Foundations • Walls • Sprayed concrete • Thin-walled precast elements • Concrete for vault construction	• Load-bearing industrial floors • Load-bearing base slabs • Elevated slabs • Load-bearing walls • Tunnel linings • Excavation pit and slope stabilization • Pipes	• Drainage surfaces • Collecting basins • Drainage channels • Gas station surfaces

1) EC2: DIN EN 1992-1-1:2011-01 [1] in conjunction with DIN EN 1992-1-1/NA:2013-04 [2].

Figure 2: Applications of steel fibre reinforced concrete for structural components and structures based on [14].

A classification with a low hazard potential is equivalent to the fact that neither building nor water law requirements are imposed on the structural component or structure made of steel fibre reinforced concrete. As already explained in Section 2.3, an abZ is also required for polymer fibres if concrete is used in accordance with DIN EN 206-1 [3] in conjunction with DIN 1045-2 [4].

For components or structures with a low hazard potential, there is also a distinction between non-load-bearing components/structures in accordance with EC2 [1, 2] or unreinforced components or structures according to EC2 [1, 2], where only the structural reinforcement is taken into account. For non-load-bearing components/structures, the residual flexural tensile strength (performance class) can be applied, whereas in the case of unreinforced members, the steel fibres may be taken into account for the serviceability limit state (SLS) design. Figure 2 shows corresponding examples of the two areas of application, such as (non-load-bearing) industrial floors (cf. Section 3.4) or open traffic areas.

In the case of requirements in accordance to building law – reinforced structural components according to EC2 [1, 2] – the guideline Steel fibre reinforced concrete [9] must be taken into account. For these components/structures made of steel fibre concrete, it is possible to apply the effectiveness of the steel fibres for both the ultimate limit state (ULS) and the SLS. Examples include load-bearing industrial floors, floor slabs and tunnel shells. Further examples are given in Fig. 2.

> **In the case of requirements in accordance to building law – reinforced structural components according to EC2 – the guideline Steel fibre reinforced concrete must be taken into account.**

If there are water law requirements for the component/structure, such as in the case of drainage surfaces and channels, collecting basins or gas station surfaces (cf. Fig. 2), the specifications/requirements of the DAfStb guideline on “Concrete construction when handling water-endangering substances“ [17] must be observed. For these components or structures, the steel fibres can be used for the minimum reinforcement or as a sealing layer with limitation of the crack width.

The following Fig. 3 is taken from the leaflet “Industrial floors made of steel fibre concrete” [13] of the German Concrete and Construction Engineering Association (DBV). This leaflet and the information contained therein are to be used “only” for industrial floors made of steel fibre concrete if these industrial floors do not have a load-bearing or stiffening function according to EC2 [1, 2]. For this field of application, the DBV leaflet is very good for designing, constructing, manufacturing and executing industrial floors made of steel fibre concrete for open-air and indoor areas with concrete compressive strength classes from C20/25 to C40/50.

As already explained, the requirements/guidelines of the steel fibre reinforced concrete guideline [9] must be observed for load-bearing or stiffening industrial floors. If waterproof industrial floors are required, the “WU Guideline” [18] of the DAfStb must be observed. If an industrial floor is exposed to substances hazardous to water, the “Concrete construction when handling water-endangering substances” guideline [17] of the DAfStb must be observed as described above.

Steel fibre reinforced concrete - Applications according to DBV leaflet “Industrial floors made of steel fibre reinforced concrete”

DBV leaflet Industrial floors made of steel fibre reinforced concrete	DAfStb guideline Steel fibre reinforced concrete	DAfStb guideline Water impermeable structures (WU guideline)	DAfStb guideline Concrete construction when handling water-endangering substances
Examples • Industrial floors subjected to loads, e.g. fork-lift truck traffic and/or racking loads (with regard to permissible racking heights, the state building codes must be observed) • Open traffic areas	Examples • Load-bearing or stiffening industrial floors • Load-bearing foundations • Load-bearing precast elements	Examples • Walls • Base slabs	Examples • Drainage surfaces • Collecting basins

Fig. 3: Industrial floors made of steel fibre reinforced concrete according to [13]

3.3 Polymer fibre-reinforced concrete Application

Section 2.2 showed that in Germany there is no corresponding regulation for polymer fibre-reinforced concrete like to the steel fibre reinforced concrete guideline [9]. Fig. 4 for the application of polymer fibre-reinforced concrete has basically the same structure as Fig. 2 in Section 3.2 for the application of steel fibre reinforced concrete.

> **"A further abZ or ZiE is required if the polymer fibres are used for the SLS and the ULS is to be applied."**

For non-load-bearing components or structures according to EC2 with low hazard potential, the approach to use the residual flexural tensile strength is possible as for steel fibre concrete, but for unreinforced components the polymer fibres cannot be applied to verify the SLS.

For components/structures with building law requirements (reinforced components), on the one hand an abZ for the polymer fibre is required for structurally effective-ness. Furthermore, a further abZ or ZiE is required if the polymer fibres are used for the SLS and the ULS is to be applied.

An abZ for the polymer fibre is also required for the water law requirements. In addition, a further abZ/ZiE and, if necessary, a water law approval must be obtained. However, this is not a useful approach, since this consideration is of a purely theoreti-cal nature and the fibre may still not be used.

Application of polymer fibre-reinforced concrete for structural components and structures

Classification	With low hazard potential (without building law and/or water law requirements)		With requirements in accordance to building law	With requirements in accordance to water law
Regulations	No load-bearing components according to EC2[1)]	Unreinforced structural components according to EC2[1)] (structural reinforcement only)	Reinforced components abZ fibre + abZ or ZiE component / structure	abZ fibre + abZ or ZiE component/structure + water law approval if necessary
Approach	Use of residual flexural tensile strength (performance class)	No verification of the serviceability limit state possible (e.g. due to creep)!	Verification of ultimate and serviceability limit states	Theoretically possible, but then the application of the fibre is not possible and therefore superfluous.
Examples	• Industrial floors • Traffic areas • Basement floors • Retaining walls up to 1.0 m terrain step • Shafts up to 0.9 m depth	• Foundations • Walls • Sprayed concrete • Thin-walled precast elements • Concrete for vault construction	• Load-bearing industrial floors • Load-bearing base slabs • Elevated slabs • Load-bearing walls • Tunnel linings • Excavation pit and slope stabilization • Pipes	• Drainage surfaces • Collecting basins • Drainage channels • Gas station surfaces

1) EC2: DIN EN 1992-1-1:2011-01 [1] in conjunction with DIN EN 1992-1-1/NA:2013-04 [2].

Figure 4: Applications of polymer fibre-reinforced concrete for structural components and structures based on [14].

For the applications "shrinkage cracking" and "fire protection", an abZ is also required (see section 2.3). In the following section, the application case "industrial floor" for polymer fibres is dealt with in detail.

3.4 Use of polymer fibres in industrial flooring

Polymer fibres are predominantly used in industrial floor in Germany. The use of polymer fibres is possible according to the DBV leaflet "Concrete industrial floors", February 2017 edition [11], but no load-bearing capacity can be applied to polymer fibres:

> In this leaflet, **unreinforced concrete slabs** are defined as designs **without reinforcement** or with **structural reinforcements** that are **below the minimum reinforcement according to (EC2)** and without steel fibres. Concrete slabs with synthetic fibres are to be treated as **unreinforced concrete slabs.**

Industrial floors become relevant under building law if ...

... they are load-bearing or stiffening.

... racking systems are installed that are load-bearing or stiffening components of a building or if the racking system only obtains its stability from the supporting structure of the building [12]. The respective state building code (LBO) regulates this decisively.

> **"In Germany, there is no document introduced under building law that regulates the design of polymer fibre-reinforced concrete if the fibre is to be used structurally."**

In these cases, a separate verification in the form of an abZ or an ZiE must always be provided for polymer fibres! In Germany, there is no document introduced under building law that regulates the design of polymer fibre-reinforced concrete if the fibre is to be used structurally. Therefore, an abZ or a ZiE must be available in addition to an abZ for the polymer fibre. A design according to EC2 as a structurally effective fibre is therefore not possible, since only unreinforced design is allowed!
The client must be informed if other codes are used (e.g. TR034). These are not part of the generally acknowledged rules of technology in Germany.

3.5 Overview of applications

In the previous sections, the application of steel and polymer fibres in concrete was presented, especially with respect to the structurally approach. Table 1 shows the applications for steel fibres and polymer fibres. For polymer fibres, a separate consideration is made for macro and micro synthetic fibres (see Section 2.3).

With steel fibres, all listed applications can be covered except for the positive influence on plastic shrinkage. The macrosynthetic fibre improves the green strength, the dry shrinkage of waterproof components and the load-bearing resistance of fatigue-stressed components. The microsynthetic fibre can be used to improve the behavior of concrete installed on slopes, as well as to reduce plastic shrinkage and increase fire protection.

Application	Steel fibres	Macrosynthetic fibres	Microsynthetic fibres
Slope	■		■
Green strength of precast elements (tunnel lining segments, pipes, sewerage elements)	■	■	
Plastic shrinkage			■
Dry shrinkage (watertight components)	■	■	
Sprayed concrete	■		
Ductility of impact- and shock-loaded components (industrial floors, guide walls, bunkers)	■		
Increase of the load-bearing resistance (fatigue-stressed structural elements)	■	■	
Improvement of abrasion resistance	■		
Replacement of structural reinforcement (foundations, external basement walls)	■		
Increase of fire resistance	■		■
Jointless (water-) tight floor slabs	■		

Table 1: Areas of application for fibre-reinforced concrete [15].

4. CONCLUSION

In the context of this white paper, the application and the fields of application of reinforced and polymer fibre-reinforced concrete in Germany have been shown. For the planner and designer, it is elementary to know all existing requirements for the component/structure in order to be able to classify it correctly.

- Is it a component or structure with a low hazard potential or are there requirements in accordance to the building law?
- Are there any other requirements, e.g. due to exposure to substances hazardous to water?

Due to the requirements and specifications resulting from this, the questions posed in section 2.1 at the beginning must be answered:

1. What are the technical requirements for the properties?
2. What are the formal requirements for the fibre to be allowed to be used in the respective area of application?

As shown, the use of steel fibres in concrete is regulated for Germany by the steel fibre reinforced concrete guideline of the DAfStb, so that there are clear regulations on design.

There are no corresponding regulations for polymer fibres. Polymer fibres may be marketed in Germany without an abZ by means of a CE mark. The use of polymer fibres without abZ is permitted in Germany for concrete in accordance with DIN EN 206-1 in conjunction with DIN 1045-2.

Polymer fibres may not be used as structurally effective in Germany without further proof, but may only be used in components/structures with a low hazard potential (without requirements in accordance to building law and/or water law) without observing further boundary conditions, if concrete according to DIN EN 206-1 in conjunction with DIN 1045-2 is not used. In this case, however, the fibres are not to be applied structurally. The residual flexural tensile strength (performance class) may be applied.

In Germany, there is no document introduced under building law that regulates the design of polymer fibre-reinforced concrete if the fibres are to be used structurally. Therefore, in addition to an abZ for the polymer fibre, an abZ or a ZiE for the component/structure must be available. A design for polymer fibres according to EC2 as a structurally effective fibre is therefore not possible, since only unreinforced design is allowed.

In summary, it can be stated that polymer fibres according to DIN EN 14889-2 can be marketed via a CE mark, but the application is only permitted with a general building approval (abZ) if building code requirements exist and/or concrete according to DIN EN 206-1 in conjunction with DIN 1045-2 is used.
The client must be informed if other regulations are used (e.g. TR034). In Germany, these are not part of the generally accepted rules of technology.

5. LITERATURE

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[19] The Concrete Society; Report TR34- Concrete industrial ground floors. Third Edition, 2003

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7. REFERENCES

SEPARATOR SYSTEM
Donaueschingen, Germany

Application:	special container
Fibre content:	30 kg/m³
Concrete:	C35/45 - LVB

ALDI DISTRIBUTION CENTER
Cardiff, Wales

Surface area:	60.000 m²
Fibre content:	45 kg/m³
Fibre type:	DE 60/1.0 N

AMAZON CENTRAL WAREHOUSE
Rheinberg, Germany

Volume:	22,000 m³ concrete
Fibre type:	DE 50/1.0 N
Capacity class:	L 1.2/0.9

BMW SPARE PARTS STORE
Gündlkofen, Germany

Area:	100,000 m²
Fibre type:	DE 60/0.9 N
Performance class:	L 1.2/0.9

FIEGE LOGISTICS CENTER
Neuss, Germany

Application:	prestressed beams
Fibre content:	40 kg/m³
Fibre type:	DE 60/0.8 M

LIDL LOGISTICS
Cloppenburg, Germany

Area:	40,000 m²
Amount of fibre:	120 t
Fibre type:	DE 60/0.9 N

METRO LOGISTICS CENTER
Marl, Germany

Area:	200,000 m²
Fibre quantity:	650 t
Fibre type:	DE 60/0.9 N

OPEL SPARE PARTS WAREHOUSE
Bochum, Germany

Area:	95,000 m²
Fibre quantity:	260 t
Fibre type:	DE 60/0.9 N

TOYS “R” US
Walsrode, Germany

Surface Area:	80,000 m²
Fibre quantity:	320 t
Fibre type:	DE 60/0.9 N