1

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1 Introduction

Around 150 years ago, urban infrastructures for supplying the townsfolk with drinking water were constructed almost exclusively with cast iron pipes. A major part of the supply network in operation today still dates back to that time. Since then the ductile iron pipe system has made enormous progress: the manufacturing processes have adapted to the increasing requirements regarding dimensional accuracy, weight reduction and efficiency. Pipe joint technology has become both more secure and simpler. The use of spheroidal graphite cast iron means that higher mechanical loads are possible while simultaneously reducing weight. Protection against chemical attack both inside and outside has been perfected and, with pipes, fittings, valves and accessories, a complete system has been produced for all tasks. Nowadays the system of ductile iron pipes, fittings, valves and accessories ensures the problem-free and cost-effective transport of predominantly liquid media (water and wastewater).

1.1 General

Essential piping networks serve for the transport of

- water (drinking water, process and industrial water) and
- wastewater (domestic, commercial and industrial wastewater).

The pipelines are predominantly laid underground and thus are not able to be inspected and monitored on any ongoing basis. Therefore they have to be constructed in a material with high resistance levels and a long working life. Their joints, too, must be durably tight against all influences from both inside and outside. Pipelines laid in the soil are exposed to many and varied stresses. Firstly there is the internal pressure necessary to convey the medium being transported. And secondly there are the external loads exerted on the pipelines above all by the soil itself and by traffic in the form of ground motion and vibrations. In addition to these internal and external loads, which usually occur in combination and may be both static and dynamic in nature, there are also chemical stresses from the surrounding soil and in some cases from the medium being carried; sometimes the influence of temperature fluctuations has to be taken into account as well.

In the main, the costs of transporting water and wastewater are determined by the costs of the pipeline, i.e. by the costs of the pipes, fittings and valves themselves, for their installation and for the operation and maintenance of the piping network.

If damage occurs to pipelines buried underground, not only is it very difficult to detect and locate this but usually it is also very expensive to remedy it. In case of damage then, in addition to the actual repair costs, the costs which have to be met for digging up and repairing modern urban road surfaces and for diverting traffic are considerably higher. Therefore sustainable piping networks must have high safety margins. Ductile iron pipe systems are characterised by the highest safety margins and meet all requirements for sustainable piping networks.

1.2 Cast iron as material for pipes

There is no reliable information about when and where the casting of iron was first discovered. However it is known that the art of iron casting was practised in China, for example, much earlier than it was in Europe.

The first iron suspension bridge was constructed there in around 300 AD. The first cast iron gun barrels were used in Europe in the 12th century.

In the first half of the 15th century remarkable achievements were already being made in the casting of gun barrels. It is probable that the first conduit pipes were also cast by gun founders on the orders of local noblemen. Obviously they very soon recognised the value of a long-lasting and pressure-resistant material for the construction of high-pressure water pipelines for their castles and fortresses. And thus cast iron set out on its path through the centuries as a piping material.

1.2.1 Old pipelines in grey cast iron

Cast iron pipes have been in use for more than 500 years, initially as grey cast iron pipes. Their long working life is legendary. At the start they were used above all for the transport of drinking and industrial water. By way of examples of the construction of old cast iron water pipelines, the following facts are known:

1455	the oldest cast iron pipeline was built; this was the pipeline supplying water for Dillenburg Castle **(Fig. 1.1)**.
1562	a water pipeline was laid in Langensalza to supply the Jacobi and Rathaus fountains.

Fig. 1.1 :
Cast iron pipe from the water supply pipeline for Dillenburg Castle (1455)

Fig. 1.2:
Flanged pipe from the park at the Palace of Versailles

1661	a water pipeline was laid for the castle in Braunfels. The cast iron pipes were in operation until 1875 and were dug up during the course of sewer laying work in 1932.
1664 – 1668	the pipeline was laid in the grounds of the Palace of Versailles to feed the water fountains there **(Fig. 1.2)**.
1710 – 1717	the construction of the cascades in the Kassel-Wilhelmshöhe castle park with the Hercules monument. Cast iron pipeline to supply the water features with water **(Fig. 1.3)**. Since June 2013 the Hercules monument along with the cascades has been a UNESCO World Heritage Site.

Since the middle of the 19th century, as a result of increasing industrialisation and the considerable growth in population with constant improvements in the standard of living, the consumption of water has been steadily rising.

Fig. 1.3:
Cast iron pipeline to supply the cascades of the Hercules monument in the Kassel-Wilhelmshöhe castle park with water (UNESCO World Heritage site since June 2013)

With the necessity of conveying ever larger volumes of water to consumers, the operating pressures in the supply lines increase.

Increasingly advanced processes for melting, casting and testing have led to improvements in the material properties of cast iron and hence also in the quality of cast iron pipes.

For the urban supply networks (drinking water) constructed since the middle of the 19th century, grey cast iron was the available material almost without exception. Later, steel came along as an additional material. The German gas and water industry statistics (Bundesverband der Deutschen Gas- und Wasserwirtschaft e. V. – BGW) for water indicate a proportion of cast iron pipes in the existing network in the Federal Republic in the 20th century, up to the nineteen fifties, of 85 %.

In this area of municipal water distribution, the main area of application for cast iron pipes since about 1960 was pipes and fitting in ductile cast iron and valves in spheroidal graphite cast iron*). The length of cast iron pipelines worldwide is estimated at several 10^7 km, of which about one third are pipes in ductile cast iron; each year several 10^5 km are added to this. The reasons for this high prevalence are, among other things

- the robustness of the pipe,
- high safety margins, even with respect to unplanned load cases,
- uncomplicated installation,

- hygienically safe for drinking water,
- the long working life of the system as a whole,
- the lowest damage rate of all piping materials,
- the lowest leakage rate,
- the lowest operating and maintenance costs,
- the fact that they can be used anywhere, from the simplest to the most difficult ambient conditions.

***) Note:**
"spheroidal graphite cast iron" and "ductile cast iron" are synonyms for a type of cast iron in which the graphite is predominantly present in spheroidal form. The expression "ductile cast iron" is normally used for pipes and fittings while the official material designation according to standard EN 1563 [1.1] for valves reads "spheroidal graphite cast iron". Where pipes, fittings and valves are mentioned in the same breath in the sections and chapters which follow, for the sake of simplicity and for easier reading, the material designation "ductile cast iron" is used.

These days, pipes, fittings and valves in ductile cast iron are the most important elements in the construction of drinking water and sewage pipelines across the world. With the more recent technological developments such as trenchless pipe laying and replacement processes and areas of application with significantly higher internal pressures or other stresses, piping systems in ductile cast iron have proved to be excellent. Ductile iron pipe systems are all-rounders for everything to do with water, whether we are talking about simple municipal water supply pipelines installed in the traditional way or the most complex of pipeline constructions with a whole range of special structures and particularly sophisticated construction processes.

1.2.2 Improvements in the production process and material properties

In order to meet increased demands, the cast iron pipe industry has developed new and more efficient production processes. In the early days, pipes were cast one by one in horizontal sand moulds and then, in 1885, the process changed to one where the pipes were cast in vertical sand moulds arranged on a series of frames, meaning that the production process could be continuous. However, the really significant innovation in cast iron pipe production was the introduction of the centrifugal casting process **(Chapter 3.3)**.

In Germany, the centrifugal casting of iron pipes has been practised since 1926. This process, which is ideally suited to mechanised mass production, enabled the pipe foundries to meet the constantly increasing demand for cast iron pipes without difficulty.

Over the course of time, cast iron has also undergone further developments as a material to adapt it to the increasing loads placed on piping networks.

For example, in around 1900 a tensile strength of at least 120 N/mm^2 was being demanded for sand-cast pipes, while by the thirties the minimum tensile strength had already reached 200 N/mm^2 for centrifugally cast pipes.

The beginning of production of pipes, fittings and valves in ductile cast iron is to be seen as the most recent and also the most significant stage in the development of foundry technology. Further details about "ductile cast iron" can be found in **Chapter 2** of this handbook.

The production of pipes, fittings and valves from ductile cast iron is described extensively in **Chapter 3**.

1.2.3 Piping systems in ductile cast iron for water supply and sewage disposal

Ductile, or malleable, cast iron pipes have been produced in Europe since 1951 and in the Federal Republic of Germany since 1956. It is the spheroidal graphite formation which makes malleability and stretching ability possible with ductile cast iron. These days the tensile strength of the material for ductile iron pipes is at least 420 N/mm². In addition to this high tensile strength, which already very clearly shows the improvement in performance, it is above all the remarkable malleability which is characteristic of ductile iron pipes.

With the improvement in the metallurgy of cast iron, the conditions are met for the use of ductile iron pipe systems in nearly all areas of the urban piping infrastructure (water and sewage).

In the water supply industry, i.e. for the transport of drinking water and industrial and process water, iron pipes and fittings in ductile cast iron have been used since the middle of the nineteen sixties. In accordance with standard EN 545 [1.2], which applies to water pipelines, the nominal sizes of pressure pipes in ductile cast iron range from DN 40 to DN 2000 in pressure classes C 20 to C 100. DIN 28603 [1.3] defines push-in joints from DN 80.

For external loads produced by the ground itself and by traffic, attention has to be paid to observing permissible ovalisation limits for the pipe of up to 4 %.

The application ranges with respect to permissible pressures are summarised in **Table 1.1** (excerpt from Table 17 of EN 545 [1.2]).

The introduction of spheroidal graphite cast iron has proved to be an advantage for valves. Because the tensile strength has been doubled, the wall thicknesses of valve bodies have been able to be dramatically reduced, thus halving the weight. There are more details about the material in **Chapter 7.1**.

In the sewage disposal industry, i.e. the transport of domestic, commercial and industrial wastewater, pipes and fittings in ductile cast iron were first of all used mainly for wastewater pressure lines in difficult terrain, e.g. in areas where there is a risk of subsidence or landslides and on steep slopes, for water crossings (culverts) and where installation conditions present static problems. According to standard EN 598 [1.4], which applies to sewers and sewage pipelines, the use of piping systems in ductile cast iron is not restricted to the construction of buried gravity pipelines.

	Pressure class (C classes) = PFA [bar]						
DN	20	25	30	40	50	64	100
	e_{min} [mm]						
80				**3,0**	3,5	4,0	4,7
100				**3,0**	3,5	4,0	4,7
125				**3,0**	3,5	4,0	5,0
150				**3,0**	3,5	4,0	5,9
200				**3,1**	3,9	5,0	7,7
250				**3,9**	4,8	6,1	9,5
300				**4,6**	5,7	7,3	11,2
350			**4,7**	5,3	6,6	8,5	13,0
400			**4,8**	6,0	7,5	9,6	14,8
450			**5,1**	6,8	8,4	10,7	16,6
500			**5,6**	7,5	9,3	11,9	18,3
600			**6,7**	8,9	11,1	14,2	21,9
700		**6,8**	7,8	10,4	13,0	16,5	
800		**7,5**	8,9	11,9	14,8	18,8	
900		**8,4**	10,0	13,3	16,6		
1000		**9,3**	11,1	14,8	18,4		
1100	8,2	**10,2**	12,2	16,2	20,2		
1200	8,9	**11,1**	13,3	17,7	22,0		
1400	10,4	**12,9**	15,5				
1500	11,1	**13,9**	16,6				
1600	11,9	**14,8**	17,7				
1800	13,3	**16,6**	19,9				
2000	14,8	**18,4**	22,1				

Note: The figures in bold indicate the standard range

Table 1.1:
Pressure classes (C classes) and minimum wall thicknesses e_{min} for ductile iron pipes in the area of drinking water supply in accordance with EN 545 [1.2];
PFA [bar] is the allowable operating pressure

They can also be used for the construction of pressure pipelines from DN 80 to DN 2000. In EN 598 [1.4] certain external stresses from soil and traffic loads are taken into account. These are applicable for a permissible deformation of the pipe of up to 4 % and for covering depths from 0.3 to 8.5 m.

More details on the design of pipes, fittings, valves and accessories in ductile cast iron can be found in **Chapters 5 to 10 as well as 14 and 15**, and on static calculations in **Chapter 16**.

1.3 Joint technology

In addition to the further development of cast iron and the production process, in order to adapt to increasing operating pressures in the piping networks improvements have also been made to the joint technology. Essentially, two types of joints are used for cast iron piping systems:

- push-in joints,
- flanged joints.

Push-in joints are generally used for underground cast iron pipelines (pipes, fittings, valves). These are flexible, rubber-sealed joints which offer both technical and economic advantages for installation.

Flanged joints tend to be favoured for pipelines above ground, as are used for example in pumping houses, waterworks or elevated tanks. As regards shut-off valves in urban water supply networks, for decades the flanged joint was also commonly used in underground pipelines for reasons of maintenance and repair. Flanged joints are restrained ones, but not moveable joints, and they transfer longitudinal and bending stresses from pipe to pipe.

The individual advantages of push-in joints and flanged joints can be combined by installing flanged sockets and flanged spigots on the flanges of fittings.

We shall look at the different types of joints in greater detail below, according to the chronological sequence of their development or their introduction onto the market.

1.3.1 Flanged joints

One of the oldest types of joints for cast iron pipes is the flanged joint **(Fig. 1.2)**. These were standardised for the first time in 1882, in the so-called “Standard components of the year 1882” produced by the German Association of specialists in gas and water (DVGW) together with the Association of German Engineers (VDI). Notwithstanding these first standards and regardless of the material being used, by 1926 the arrangement of the bolt holes had already been determined in such a way that the bolt holes lie symmetrical to both principal axes and their number is divisible by four in all nominal sizes.

The joint dimensions of cast iron flanges (external diameter, bolt hole circle diameter, raised face diameter, number and diameter of bolts, bolt hole diameter) are determined in EN 1092-2 [1.5]. Additional construction dimensions for PN 10 to PN 40 flanges are also given in this EN standard. A flanged joint consists of two flanges, a sealing element and a certain number of hexagon head bolts with nuts and washers. The material of the sealing element depends on the purpose of use in each case. The flanges of ductile iron pipes, fittings and valves are provided with raised sealing faces. **Fig. 1.4** shows a flanged joint of this kind (nuts to EN ISO 4034 [1.6] and hexagon head bolts to EN ISO 4016 [1.7]).

Fig. 1.4:
Flanged joint

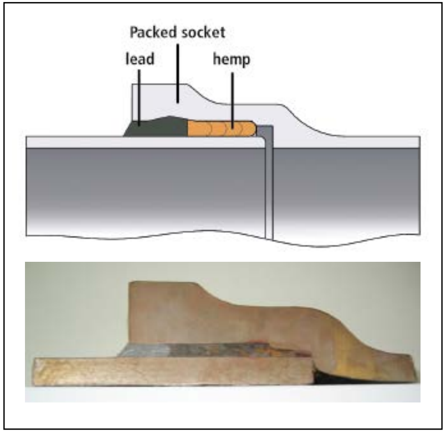


Fig. 1.5:
Packed socket joint

Fig. 1.6:
Cut section of a packed socket joint from an approximately 300 year old cast iron pipe – water supply pipeline for the cascades at the Kassel-Wilhelmhöhe castle park with the Hercules monument; UNESCO World Heritage site since June 2013
Source: mhk, Museumslandschaft Hessen Kassel

1.3.2 Packed socket joint

Until the introduction of rubber-sealed socket joints (around 1930) pipes and fittings in grey cast iron were mainly joined by means of packed sockets. These were not restrained joints. The packed socket joint **(Figs. 1.5 and 1.6)** is rigid and is not tight in case of movement.

The pipe joint is of immense importance for the reliability of a pipeline. In the area of cast iron pipes, the advantages of rubber-sealed socket joints were recognized very early on. After all, the rubber seal gives the pipeline flexibility which allows it to adapt to the stresses produced by traffic vibrations and ground movements as well as strain and compression forces in the pipe run without any adverse effects on tightness at the connection points.

Chapter 13 contains more details about the different types of sealing elements.

1.3.3 Screwed socket joints

The screwed socket joint has been used in Germany since 1931. Structural design and dimensioning are determined in detail in DIN 28601 [1.8]. **Fig. 1.7** shows the joint in cross-section.

The inside of the socket and the outside of the screw ring are buttress-threaded according to the direction of load. A screw ring axially compresses the elastic sealing element, which has hard rubber protective edges at the front and back, into its seating via a sliding ring. This produces the seal between the socket and the spigot end. The protective edges prevent the soft rubber part under compression in the middle from being forced out into the sealing gap.

The necessary angular deflections – the joint allows deflections of up to 3° from straightness – are only produced during installation after tightening the screw ring. These days the screwed socket joint is only used for fittings in the range from DN 40 to DN 400. A restrained joint can be produced by using additional elements. More on this in **Chapter 9**.

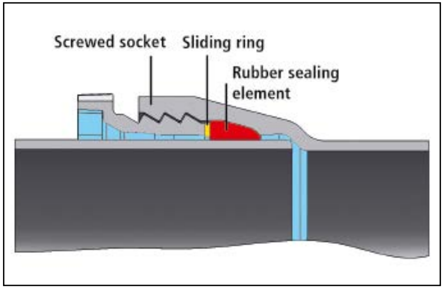


Fig. 1.7:
Screwed socket joint

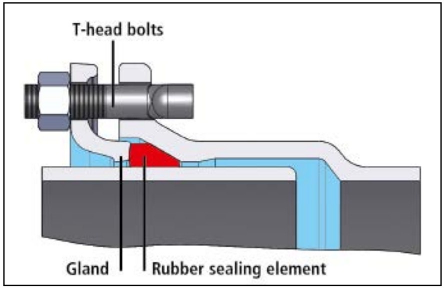


Fig. 1.8:
Bolted gland joint

1.3.4 Bolted gland joints

The bolted gland joint has been in use in Germany since 1936. Its dimensional construction is covered in DIN 28602 [1.9]; **Fig. 1.8** shows a cross-section.

Here it is the gland which applies pressure via T-head bolts onto the wedge-shaped sealing element, which has a hard rubber protective edge on the front. The sealing principle is practically the same as with the screwed socket joint. The necessary angular deflections – the joint also allows deflections of up to 3° from straightness – are only produced after the joint has been assembled. These days the bolted gland joint is only used in combination with certain types of fittings in the range from DN 500 to DN 1000.

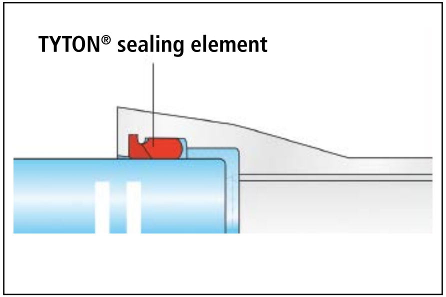


Fig. 1.9:
TYTON® push-in joint

1.3.5 Push-in joints

Nowadays, rubber-sealed push-in joints according to DIN 28603 [1.3] are predominantly used for ductile iron pipelines: the TYTON® push-in joint system has applications for the range between DN 80 and DN 1400, while the STANDARD push-in joint system is used in the range from DN 80 to DN 2000.

The TYTON® joint **(Fig. 1.9)** has been used in Germany since 1957. The profiled sealing element is produced from a mixture of hard and soft rubber.

Detailed information about push-in joints and their area of use can be found in **Chapter 8**.

1.3.6 Fields of use

The fields of use according to pressure classes (C classes) and minimum wall thicknesses e_{min} for ductile iron pipes in the field of water supply are shown in **Table 1.1**. In the field of sewage transport, ductile sewers as per EN 598 [1.4] are standardised for gravity pipelines up to 6 bar operating pressure. For higher pressures, pipes of pressure classes (C classes) according to EN 545 [1.2] are to be selected.

Special cases, such as the construction of a culvert pipeline or where there is a low cover depth, higher internal pressure loads or special linings and coatings can be dealt with by additional measures, either during production or during installation.

1.4 Modern ductile iron pipe techniques

The ductile iron pipe systems used today meet the requirements which are to be demanded of new piping networks for the transport of water and wastewater to a particularly high degree; there are additional fields of application in the field of industrial pipelines, e.g. for

- turbine pipelines for power production,
- snow-making equipment,
- fire extinguishing pipelines,
- cooling water pipelines.

But, because of their high loading capacity, ductile iron pipes have also opened up new fields of activity in construction technology, e.g. for

- trenchless laying techniques,
- foundation piles.

Corresponding details are covered in **Chapters 22 and 23**.

Ductile iron pipe systems owe their excellent properties above all to the following features:

- the modern jointing technology in the form of push-in joints including the flexible restrained push-in joints,
- the remarkable strength and stability of the material,
- the highly developed types of corrosion protection in the form of linings and coatings suited to specific tasks.

They offer high degrees of security against the stresses produced by the highest internal pressures. In addition, the material means that they resist practically all ground and traffic related loads.

Quite particular emphasis should be placed here on their ability to resist the resulting crushing and bending stresses, as it is precisely these types of stress which are considerably reduced by the flexible, rubber-sealed push-in joints.

The possibility of also providing such ductile iron pipes, fittings and valves with adequate external protection depending on the aggressive nature of the soil takes account of the practical realities during the installation of pipelines.

A comprehensive description of the various types of coatings can be found in **Chapter 14**.

All system components for the transport of drinking water, operating and process water or sewage are basically provided with appropriate linings in accordance with EN 545 [1.2] and/or EN 598 [1.4]. In particular this includes cement mortar and polyurethane linings for pipes. Fittings and valves are mainly coated all around with epoxy resin or enamel. **Chapter 15** contains details about linings.

1.5 Sustainability

In recent times, the term “sustainability” has gained increasing importance when assessing infrastructure investments. In such a consideration, economic, environmental and technical aspects are examined and evaluated, and this applies to the entire working life of the product.

The key points of sustainability criteria for ductile iron pipe systems with respect to an economic, environmental and technical assessment are shown in **Tables 1.2, 1.3 and 1.4** [1.10].

Table 1.2:
Economic sustainability criteria for ductile iron pipe systems

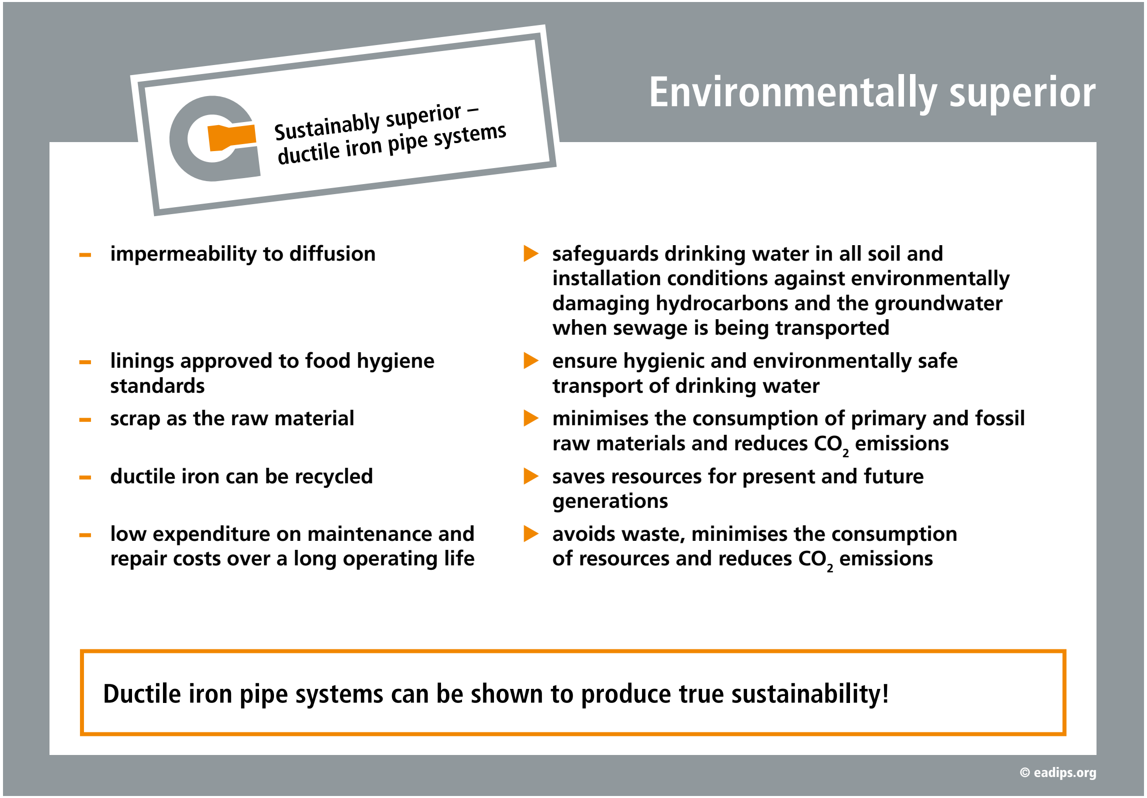
Sustainably superior – ductile iron pipe systems

Economically superior

push-in joints make for highly productive installation	▶ reduces labour costs
no welding needed	▶ reduces labour costs
installation in all weathers	▶ reduces labour costs
sand bedding often not required	▶ reduces materials and logistics costs
concrete thrust blocks not needed when joints are restrained	▶ reduces materials and logistics costs
joints can be deflected angularly	▶ saves on fittings
wide range of fittings and valves available so no need for specials	▶ reduces materials and labour costs
extremely low damage rates	▶ reduces operating, energy, repair and maintenance costs
operating life of up to 100 years or more	▶ keeps renovation budgets to a minimum

Investing in ductile iron pipe system pays for itself in low installation and operating costs with, at the same time, an extremely long operating life!

Table 1.3:
Environmental sustainability criteria for ductile iron pipe systems



Sustainably superior –
ductile iron pipe systems

Environmentally superior

– impermeability to diffusion	▶ safeguards drinking water in all soil and installation conditions against environmentally damaging hydrocarbons and the groundwater when sewage is being transported
– linings approved to food hygiene standards	▶ ensure hygienic and environmentally safe transport of drinking water
– scrap as the raw material	▶ minimises the consumption of primary and fossil raw materials and reduces CO_2 emissions
– ductile iron can be recycled	▶ saves resources for present and future generations
– low expenditure on maintenance and repair costs over a long operating life	▶ avoids waste, minimises the consumption of resources and reduces CO_2 emissions

Ductile iron pipe systems can be shown to produce true sustainability!

Table 1.4:

Technical sustainability criteria for ductile iron pipe systems

Sustainably superior – ductile iron pipe systems

Technically superior

the material is strong	allows operating pressures up to 100 bars
effective external protection	shields against mechanical and chemical attack
static load-bearing capacity	allows very high stresses in the transverse and longitudinal directions
joints	allow operating pressures up to 100 bars; are resistant to root penetration
ductile iron	is non-combustible
installation	is possible with no special equipment
restrained joints	allow very high tractive forces and are therefore ideal for trenchless installation
the material has superior properties	which allow special applications in mountainous regions and for fire-fighting pipelines, snow-making systems and hydroelectric power stations

The technical performance of ductile iron pipe systems ensures the highest safety and reliability in all areas of the water industry!

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1.6 Summary

Ductile iron pipe systems with their highly developed technology offer many advantages. With the push-in joint they are simple, safe and fast to install and are durably tight. They also stand up to diverse loads from both inside and outside. Installation, maintenance and follow-up costs are particularly low.

Consequently the ductile iron pipe system has an extremely long useful life.

With a multitude of technical advantages and practical operational properties, ductile iron pipe systems are seen as an economic and therefore sustainable solution for water supply and sewage disposal over the long term.

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