Ductile iron pipes and fittings

1. History

1.1. *Cast iron used since 15th century*

The first cast iron pipeline was built at Dillenburg in Germany in 1445. The oldest cast iron pipeline still in service is that of Langelsalza in Germany built in 1562. Pipelines at Versailles built in 1644 are still being used, another pipeline built in London in 1749 still supplies water there.
It is interesting to note that the first flexible joint was designed by James Watt in 1810 for a 15″ line in Glasgow.

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In America over 100 towns have been equipped with cast iron pipes for over a century, these lines having been built from 1819 to 1890. It is also worth noting that the total length of cast iron mains in the USA represents around 640,000 km.
This illustrates the good resistance of cast iron to the aggressive action of the soil. This resistance is due to the iron remarquable property of self protection. When aggressiveness is encountered, at first corrosion takes place, but the products of the corrosion stay on the surface of the iron and act as a barrier to further destructive action. This outer skin made up of products of the oxydation of the iron plus the free carbon, also reinforced by the silicum slows up the ionic exchange. This has been proved by laboratory and site tests, and a few curves illustrate this property.
The efficiency of this barrier is all the more as it becomes thicker, the limit can be placed around 6 to 7 mm of equivalent iron when the protection will be sufficient to stop further corrosion of the pipe in almost all types of ground.

1.2. *Ductile replaces gray iron*

A great weakness of gray iron is its fragility which limited its use under modern site and working conditions.
For some time, the fragility of gray cast iron had been the major concern of the founders. The fragility of gray cast iron is due mainly to the carbon which at the same time in the main anti-corrosive agent. In fact, the laminated structure of the carbon in the matrix of the material is a major cause of failure under strain.
It was obvious if the carbon could be made to solidify in a spherical shape, the mechanical properties of the metal would be greatly modified, a greater elongation before failure under strain would be obtained.
In 1948, at the same time in America and England it was discovered that if a molten charge of iron was solidified in the presence of magnesium or cerium, the free carbon in the matrix was spherical in shape. The structure of ductile iron can vary from ferritic to perlitic. More it is ferritic, the longer % elongation are obtained, however the elastic limit is correspondingly reduced, on the other hand the more it is perlitic, the higher are the elastic limits, but the % elongation is reduced.
Pipes are long and slender and the ferritic iron used in their manufacture is specified in the different standard; the guaranteed % elongation is never less than 10 % for diameter 1000 mm and below, and in fact varies between 10 and 15 %; above 1000 mm the minimum % elongation is 8 %.
In case of specials which are short and where the bending moment in much less, the iron has a specified minimum elongation of 5 %. Furthermore the casting of specials with a less ferritic ductile iron is easier, thus permitting a more economical manufacture.
Having discovered a new iron which had lost the fragile nature of its predecessor, it was then necessary to find out if it had kept its anti-corrosive properties. Thus many laboratory and site tests have been carried out since 1950 in France as well as abroad; and it is now possible to state if anything that resistance to corrosion of ductile iron is better than that of gray iron.

2. Specification

2.1. *Gray iron - Pipes and fittings*

International Standard, ISO R 13.
French Standard, AFNOR A 38011.
German Standard, DIN 28500.
British Standard, BSS 1211.

Spun gray iron:

Chemical analysis: C = 3.5 %, Si = 2.0 %, P = 0.8 %.
Mini tensile strength: 200 N/mm².
Brinell hardness: less than 230.

2.2. *Ductile iron - Pipes and fittings*

International Standard, ISO/DIS 2531.
French Standard, AFNOR A 38012.
German Standards, DIN 28500 Technical Specification, DIN 28610 Tyton joint, DIN 28614 Flanges Pipes & Fittings.
British Standard, BSS 4772: 1971.
American Standards, ANSI A 21.50-1971 Design of pipes and fittings, ANSI A 21.51-1971 Pipes, ANSI A 21.10-1971 Fittings, ANSI A 21.4-1971 Cement lining, ANSI A 21.5-1972 Protection with PE wrap.

Chemical analysis: C = 3.2 to 3,8 %, Si = 2 to 3 %, Mn = 0.30 %, Mg = 0.06 %.
Elastic limit greater than 320 N/mm².
Mini tensile strength 420 N/mm².
Mini % elongation 10/8.
Hardness Brinell less than 230.

2.3. *Advantages of ductile iron on gray iron*

Ductile because of its better mechanical properties enables lighter and stronger pipes and fittings to be produced without loosing the inerant resistance to corrosion of gray cast iron.
These lighter pipes and fittings which will resist to bad handling and makes easier and safer the building of pipelines which have better performances to satisfy modern conditions.

3. Characteristics of ductile iron pipes and fittings

3.1. *Reduction of weight, classes*

The formula for pipe thickness as used in ISO/DIS 2531 is $c = K (0.5 + 0.001 DN)$. The standard class is that equivalent to K = 9. Nevertheless in large diameter ≥ 800 mm classes of K = 7 of 8 can be retained depending on the working pressure encountered.
As an example: an 800 mm diameter gray cast iron pipe of LA thickness for a working pressure of 10 bars weighs 379 kg a m, where an equivalent K 9 ductile iron pipe for a working pressure of 25 bars weighs 279 kg a m. This order of saving of weight will be found on the whole range from 80 mm to 1600 mm with a parallel increase of working pressure.

3.2. *Higher strength*

The higher strength of the metal enables the maximum working pressure of the standard ductile iron pipe to be increased considerably as compared to the previous LA gray iron class.

Ø	Ductile iron K 9 bars	Gray iron LA bars
60 to 100	40	25
150 to 200	40	18
250	39	16
300	37	15
350	35	14
400	34	13
450	33	13
500	32	13
600	31	12
700	27	12
800 to 1100	27	11
1250	27	10

3.3. *Possibility of improving resistance to aggressive grounds*

The life of a pipeline rests on the capacity of the metal to resist corrosion from outside as well as from inside, the metal must also stand up to the stress caused by the operation of the pipeline.

Corrosion, the most important destructive element is a complex process governed by microbean and electric influences, acting separately or together. Past experience in the field as well as in the laboratory confirmed that the pure carbon in cast iron is an essential factor in its resistance to corrosion. Chemically cast iron contains in volume from 10 to 12 % of free carbon; furthermore other elements than iron are also present such as 2 % silicium, etc.

In a corrosive action, the non ferric elements are not affected and form a screen between the remaining iron and the attacking agent, the iron being always the first element to be attacked.

It is important to note that if by some means or another this phenomena of auto protection as described above is not allowed to take place, the rate of corrosion of cast iron will destroy the metal completely, but such experiments do not represent the reality.

A pipeline which presents electrical continuity incites the circulation of electrical currents of artificial or geological origin in the pipeline. These currents can deteriorate the pipeline where they leave it, but by dividing the pipeline up into sections, and in practice if these are around 6 meters long, sufficiant protection is ensured against electrical corrosion, and this is the case for cast iron pipe where the joint is naturally insulating. In the case of a continuous metallic pipeline where it is not possible to include joints economically, the only possible remedy is to equip the pipeline with a continuous coating to insulate it from the soil and at the same time to force an electrical current through to compensate any outside electrical action if the insulation came to fail. This process is well known as cathodic protection.

This cathodic protection is thus an artificial means and as such calls for specialized man power, and continuous supervision during the life of the pipeline with all the risks and implications which go with it.

I must insist on the important fact that cast iron pipelines in gray or ductile iron because of the joints which insulate them do not need any special maintenance to insure a long life once they have been built.

3.3.1. Loose PE sleeving

However, the increasing density of population all over the world is forcing development of ground whatever its nature; this also applies to pipelines. Severe aggressive grounds are now met which even can damage a ductile iron pipe; and it has now became necessary to be aware of such a possibility. In America and in Europe has been developped a very efficient and simple way of protecting ductile iron pipelines against microbean action, these pipelines are already not affected by stray currents because of natural insulation of the joints: by using a loose polyethelene sleeve placed on the pipe during laying. This protection strenghthems the self protection qualities of ductile iron and enables the pipe to face highly aggressive conditions.

Simple methods of evaluation the aggressivity of the ground are used and when a certain criteria is reached loose sleeving is placed with unskilled labour without delaying the laying work. This protection has now been in use for 20 years in the USA and its effectiveness proved by periodical inspections. Over 900 km of ductile iron pipes have now been so protected there. In France our first use of polyethelene sleeve was in 1964 and an inspection carried out in 1971 showed the pipeline to be as new. We have in France and overseas now protected over 1,500 km of ductile iron pipe lines from Ø 60 to 1,250 mm.

3.3.2. Zinc metallization

The life of a cast iron pipeline depends in 95 % of the grounds in which these lines are placed on the capacity of the iron to build up a protective screen of corrosion products.

Experience has proved that the minimum safe thickness of wall to satisfy the above conditions is around 6 to 7 mm.

In the smaller diameter range it has been necessary for reason of economics to use thinner walls than 7 mm, and a special metallized zinc outside coating has been developped which more than compensates the lesser thickness of iron.

This zinc coating which is metallically sprayed on the pipe surface in the case of aggressive grounds slowly transforms itself into hard and compact skin of zinc corrosion products which slows up the attack of the ground and linked with the iron's natural protective action ensure the necessary life expectancy of the pipeline.

The coating is done to a charge of 140 g/m^2 of surface. The zinc must be pure. This zinc coating is sealed with coal-tar base varnish which seals the pores of the zinc coating and slows up its transformation into soluble hydroxyde and permits the slow built up of a tough skin of insoluble zinc corrosion products. The coating is placed at the factory.

The use of loose PE sleeving is retained if the aggressivity of the ground reaches fixed criteriae and allows for the 5 % of grounds which can be considered as dangerous for iron pipes of minimum thickness of 7 mm.

3.3.3. Cement lining

Up to now I have only dealt with outside corrosion of pipelines. Corrosive action can also take place inside, but generally is much less critical, the aggressive agents are less active and easier to control. Cast iron suffers no corrosion in most cases, however, tubercolation can take place if the water transported is very acid, which reduces the capacity of the pipeline.

For more than 30 years, American engineers have noted that by using a cement lining in their pipelines, on the one hand no tubercolation takes place and that on the other hand loss of head has not increased over the period. The spun iron pipe is most suited for the spinning of the cement lining, which gives a uniform and smooth finish, and for this reason it has replaced the other bituminous products which can also be used.

My collegue, dr. W. Schwenk, will go into more detail in the mechanism of the protection by cement lining and its advantages.

4. Design and code of practice

4.1. *Design of ductile iron pipe*

The thickness of ductile spun iron pipes is governed by:

1. inside pressure
2. outside loads
3. environment.

4.1.1. Inside pressure

The practice is to define classes of pipe from the formula used in the ISO/DIS 2521:

$e = K\,(0.5 + 0.001\ DN)$

For $K = 9$ we have given the maximum working pressures in Chapter 3.2.

4.1.2. Outside loads

The governing factor is the stress on the metal which should be limited to 80 % of the elastic limit that is 254 N/mm^2. This gives an ovalization from 3 to 4 % and can not harm the inside lining.

Outside loading

This is calculated as follows:

$Wc = We + Wt$
$We = H.w.Bc$
Wt = live loads

We: weight of backfill per m. of pipe
H : height of backfill
w : volumetric mass of backfill: 1920 kg/m^3
Bc : exterior diameter of pipe.

Stress in the pipe wall

$$f = \frac{12 \cdot Wc \cdot d}{4 \cdot e^2} \left(Kb - \frac{Kx}{\frac{8E}{E'}\left(\frac{e}{d}\right)^3 + 0.732} \right)$$

f : stress: 80 % of elastic limit 254 N/mm²

e : thickness of wall

d : mean diameter of pipe

Kb: bending moment coefficient depending on bedding angle

Kx: deflection moment coefficient depending on bedding angle

E : longitudinal modulus of elasticity of metal 170.000 N/mm² for ductile iron)

E' : modulus of soil reaction depending on conditions of backfilling (see below)

a. Condition A

Loose backfill
E' = 1,06 N/mm²

b. Condition B

Well damed backfill on sides of pipe (this is the usual one retained)
E' = 2,11 N/mm²

c. Condition S

In the case of high backfill, the bedding angle is taken as 120° and the backfill carried out in granulated material or damed to 90 % Proctor.
E' = 4,92 N/mm².

Ovalization

$$\Delta x = \frac{12 \cdot Kx \cdot Wc}{8E\left(\frac{e}{d}\right)^3 + 0.732\,E'}$$

Method of assessing soil agressivity

Abbreviations		Factor
	I - Soil composition	
C	Chalky soil	+ 2
S	Sand	+ 2
CA	Chalky clay	+ 1
CM	Marly chalk	+ 1
SM or SA	Marly sand or clay	+ 1
LC	Silty chalk	+ 1
L	Silt	0
SAB	Sandy clay 75 % mud	0
SLB	Silty sand 75 % mud	0
LM	Silty Marl	— 1
LT	Peaty silt	— 1
A	Clay	— 2
AM	Marly Clay	— 2
H	Humus	— 2
M	Marl	— 3
TS	Thick silt	— 3
TB	Muddy ground	— 4
TM	Swampy ground	— 4
T	Peat	— 4
	II - Soil condition	
	Underground water present at level of pipe line	
ENP	— none	0
EP	— present	— 1
EV	— part time present	— 2
SN	Natural soil	0
Sr	Backfill	— 2
S = f	Same soil as trench	0
S ≠ f	Soil different to that of trench	— 3
	III - Measured specific resistance	
	> 10,000 ohms/cm	0
	10,000 to 5,000 ohms/cm	— 1
	5,000 to 2,300 ohms/cm	— 2
	2,300 to 1,000 ohms/cm	— 3
	< 1,000 ohms/cm	— 4
	IV - Water contents	
	< 20 %	0
	> 20 %	— 1

Abbreviations		Factor
	V - pH reading	
	pH > 6	0
	pH ≤ 6	— 2
	VI - Redox potential at pH 7	
	E > 400 mv	+ 2
	+ 200 to + 400 mv	0
	0 to + 200 mv	— 2
	E < 0	— 4
	VII - Concentration in carbonates	
	> 5 %	+ 2
	1 % to 5 %	+ 1
	< 1 %	0
	VIII - H2S and sulphides	
A	None	0
T	Trace	— 2
P	Present	— 4
	IX - Coal and coke	
A	None	0
P	Present	— 4
	X - Chlorides	
	Concentration:	
	< 100 mg/kg	0
	≥ 100 mg/kg	— 1
	XI - Sulfates	
	Concentration:	
	< 200 mg/kg	0
	200 to 250 mg/kg	— 1
	500 to 1000 mg/kg	— 2
	> 1000 mg/kg	— 3

Sum of factors	Aggressivity
> 0	Not aggressive
0 to — 4	Weakly aggressive
— 5 to — 10	Aggressive
< — 10	Very aggressive

4.1.3. Environment life

As said before there are a few grounds that can be harmfull to ductile iron pipes of minimum thickness of 7 mm or coated with zinc if less. Passed experience shows the chances are up to 5 on a 100 sites.
If the conditions on the area are unknown, geological maps are studied to get a first impression of the possible ground conditions, and if necessary further information is collected.
First of all, the resistivity of the soil is measured and if below 2500 ohms x cm² the use of loose PE sleeving is imposed. However this criteria is not sufficient when the resistance is higher and further tests must be carried out on soil samples to check for presence of sulphides, chlorides and sulphates and other factors.

Use is then made of Stanrath method to assess the aggressivity and the results are interpreted to decide if loose PE sleeving is however necessary.

4.2. *Code of practice*

The same practice should be followed for the laying of ductile iron pipes as that well known for gray iron. Nevertheless the danger of damaging the pipe during laying and operation has disappeared and need not to be feared.
The same methods of hot tapping can be used on ductile iron as with gray.
The cutting of ductile pipe differs in as much that the material being elastic snap-pop cutters can not be used. But there are different types of suitable equipment on the market. The emery wheel cutter is a very popular equipment and can be used on all sizes of pipe.
Ductile iron can be welded but this necessitates special electrodes and experienced welders.

5. Economics

5.1. *Possibility of improving service*

Ductile pipelines with their high strength permit increase working pressures when the conditions of operation became more acute, and thus do not become osbolate so soon, and gives more value for the money.

5.2. *Low costs of installations and maintenance*

Although basic prices of ductile pipes and fittings may be more costly than other materials, the lesser laying costs compensate in the final price and when is included the operational costs of the pipeline a saving on the whole is obtained.
In other words, basic price of ductile iron pipe is not a criteria for judging the final cost of the construction when compared to other materials.

5.3. *Pipeline designed for site conditions*

The versibility of ductile iron as much in the manufacture when different thickness can be obtained, as during site laying, when added protection can be used on the standard pipe, without delaying the work; this is an important for engineers so as to give the best service with the least cost. Ductile iron pipe lines can be taylor made with no extra cost.

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