

SELECTION OF PIPE MATERIAL FOR LARGE DIAMETER WATER MAINS

SUMMARY

In this paper all the different materials for large water mains are examined in order to assist engineers in the selection of the best alternative in projects involving multi million dollar investments. Four pipe materials are examined (Steel, Ductile Iron, Reinforced concrete and Fiberglass) and in order to make these complex systems work and last maintenance free for a long time, special attention is devoted to corrosion protection.

The choice of the material for a water line of diameter from 1000 mm to 3000 mm depends from the characteristic of the conveyed fluid, of the soil where the pipe is supposed to be laid, from the working conditions affecting the pipes, namely external loads, seismicity, working pressure, transient conditions) and at times also from particular local conditions that can be encountered in impervious zones or crossing roads, densely inhabited areas, waterways etc. Also a considerable importance rests on the costs related not only to the pipes but also to installation, to transport, to custom duties and to delivery times

It must be highlighted that the success of the construction depends on the soundness of the design and the strict respect to its specification

The characteristics that large diameter water pipes must possess, apart from the manufacturing techniques and laying criteria and methods, are:

- mechanical resistance to internal and external loads
- resistance of physical, biological and chemical nature related to the quality of the conveyed water and to the soil
- flow resistance (smoothness) that must be the lowest possible
- ease and safety of installation
- comprehensive optimal cost, considering not only materials and installation but also maintenance and duration

This document examines the following materials characteristics: Ductile Iron, Steel, Reinforced Concrete, GRP (Fiberglass) because these are the only materials that have a good performance in sizes up to 3000 mm.

In the following table a list of options is shown as reference describing their main characteristics and their international codes and standards (Martino - 2001).

Table 1 - Pipe's material: main characteristics and international standards

Material	Relevant manufacturing standards and codes	Coatings e: external i: internal	Diameter range	NP (atm)	Main field of application in the water sector
			Diameter (mm)		
Metallic					
Steel	UNI 6363/84	e: bitumen plastic (poliet.)		according to design	Intakes and mains of medium to large diameter (500 < ND <3000)
	UNI 7272		40-2700		
	ISO 559/77	i: epoxy - cement			
Ductile iron		e: bitumen zinc alloy Zn+Al	40-2000	10-16 (up to 2000 mm)	Connecting Pipelines
	UNI EN 545	i: epoxy cement centrifugated	60-300	40 for ND <300	distribution networks (D < 500)
Composites					
GRP	UNI 9032 / 08 EN 1796 EN 705		25-3000	up to 20 bar	Intakes and mains of medium to large diameter (500 < ND <3000)
Concrete					
Traditional reinforced concrete	UNI EN 642	i: cement malta		low pressure (NP < 3)	Intakes and mains of medium to large diameter (500 < ND <3000)
	AWWA – C 602-76	e: light bitumen	600-3000	up to 17	
Reinforced concrete steel lined		e: light bitumen	2000-2500	up to 20	
c.a.d (tad)	UNI EN 640		500-1400	<10	Mains and distribution. Low pressure for irrigation

The above table has been drafted based on investigations of the most important italian aqueduct systems in the civil and irrigation sectors.

For large mains both for civil and irrigation use the materials that are by far most used are Fiberglass and Steel and in a lower scale Reinforced concrete. Ductile Iron finds application in a large spectrum of diameters for mains of medium size 500 mm to 1200 mm. For DI a new kind of external coating has been introduced Metallic type base on a zinc-aluminium alloy to improve the resistance characteristics to external aggression. On top of this coating an epoxy finishing coat is applied to saturate any residual porosity.

PIPES IN CONCRETE CONGLOMERATE

Concrete pipes are classified into 2 fundamental categories:

- Normal reinforced concrete
- Prestressed reinforced concrete

Reinforced concrete pipes, with the actual manufacturing technologies and with the available codes and standards, are a viable and competitive offer for the construction of big mains of large diameter and low pressure (usually not more than 3 atm) also in relation to pressure surges.

The present manufacturing methods are finalised to achieve high levels of impermeability, density and mechanical resistance. These results can be obtained through centrifugation and/or vibration of the mould.

The joints are bell and spigot and sealing is guaranteed by an elastomeric toroidal gasket; lately pipes with steel lining in contact with the gasket are finding wider use.

It is worth mentioning also the prestressed concrete mains surrounding a steel cylinder according to AWWA C – 301 that have a certain diffusion in North America and Australia.

STEEL PIPES

Steel used for this production of water Mains pipes is normal construction steel and its typical chemical composition is mainly defined by the carbon, manganese, and silica content.

The steel production is generally divided into two fields:

- welded pipes
- seamless pipes

The UNI 6363 code refers to non-alloy quality steel, welded and seamless, for potable water use. In it the applicable codes and standards are found for the relevant mechanical testing and material classification. The manufacturing process is taken into consideration in its entirety: procedure for steel yielding, deoxydation, manufacturing process for welded and seamless pipes.

Herebelow in the table typical metallurgical characteristics are listed of chemical compositions and mechanical resistance.

Table 2 –Chemical composition (percentages)

Steel Quality	C % max	Mn % max	Si % max	P % max	S % max
Fe 360	0,17	1,20	0,35	0,040	0,040
Fe 410	0,21	1,20	0,35	0,040	0,040
Fe 510	0,26	1,30	0,50	0,040	0,040

The fundamental data regarding mechanical characteristics are reported below.

Table 3 –Mechanical characteristics

Steel Quality	Ultimate Tensile Load R_m (N/mm²)	Yield Load R_s (N/mm²)	Percentage elongation A (%)
Fe 360	360	235	25
Fe 410	410	255	22
Fe 510	510	355	20

Joints are mainly welded for large diameter pipes.

DUCTILE IRON PIPES

Ductile iron has completely different properties from those of steel; it contains carbon percentages in the order of 2 to 4 %.

In spheroidal ductile iron, used for pressure pipes, thanks to special methods the graphite precipitation is obtained in spheroidal form, in a form that has the minimum surface and therefore does minimum damage to the surrounding matrix allowing the optimisation of the mechanical characteristics and gaining ductility.

To obtain specific mechanical properties a variety of specific thermal treatments exist among which the most important are: stabilisation treatment, reheat, normalisation, regeneration and superficial treatments.

Table 4 –Ductile iron composition

	C %	Si %	Mn %	P %	S %
Spheroidal DI	3,30-3,80	1,80-2,80	≤0,60	≤0,10	≤0,0.

Table 5 – Ductile iron mechanical characteristics

Type	Ultimate Tensile Load R_m (N/mm ²)	Unit Load for plastic deformation R_p 0,2 min N/mm ²	Percentage elongation A (%)
Pipes (centr.) DN 40-1000 mm	420	300	10
Pipes (centr.) DN 1200-2000 mm	420	300	7
Cast pipes DN 40-1000 mm	400	300	5
Fittings	400	300	5

The applicable code is UNI EN 545. It gives the necessary code guidelines, gives the technical prescriptions on the dimensions and on the pipe and fittings material characteristics and describes the internal and external linings and optional protections. For each coating all the characteristics are specified, their application method and the testing procedures with reference also to the fittings and accessories on which the zinc coating have to be applied (smooth ends) bitumen coating (flanges and bells). All joints and accessories are listed in order to make consultation easier.

Pipes produced in Europe in the range 40 mm to 2000 mm are generally with a bell and spigot joint and elastomeric rubber seal.

FIBERGLASS PIPES (GRP)

GRP comes into the categories of “composites” materials. Applicable standards are : ASTM/AWWA C950/95 & manual M45 American Water Works Association - Standard for fibreglass pressure pipes

The glass fibers are responsible for the mechanical characteristics of the product. The very small cross-sections minimize the chance of defects and so the material comes close to its theoretical strength. For example, the glass fibers normally used in GRP have a tensile strength of about 18.000 Kg/cm², higher than that of the best steels.

Furthermore, the reinforcing material can be arranged with any desired density and orientation, allowing the technical and economic characteristics of the structure to be optimized.

There are several technologies for the manufacture of GRP pipes. The highest mechanical performance is obtained in pipes produced by continuous winding of filaments on a male mould (filament winding), since the quantity of reinforcement that can be incorporated in the matrix is higher. All GRP pipes comprise at least three layers, perfectly connected one to the other but with different functions. The inner layer (liner), in direct contact with the fluid, provides the highest chemical resistance and impermeability. The intermediate layer is structural. The other (gel-coat) protects the fibers externally from abrasion and atmospheric agents.

The characteristics shown in the table are those commonly encountered in pipes produced by filament winding.

Properties	Value	Unit
Density	1,7÷1,9	Kg / cm ³
Tensile strength (circumferential)	220 - 250	N/mm ²
Tensile strength (axial)	110	N/mm ²
Elongation at break	> 1,4	%
Modulus of elasticity (axial)	10,000 - 14000	N/mm ²
Modulus of elasticity (circumferential)	20,000 - 25,000	N/mm ²
Linear coefficient of thermal expansion	0,02*10 ⁻³	°C ⁻¹
Resistance to shearing impact (Charpy)	> 100	Kg cm / cm ³
Thermal conductivity	0,26	W / m*K

The characteristics shown above are valid for wide ranges of temperatures, depending on the type of resin used.

GRP has excellent chemical and electrochemical resistance; the most commonly resin used for water application is polyester cured according to the manufacturer's standard that is also resistant to the most corrosive chemicals. The temperature limit for the use of GRP materials is generally around 100°C

COATINGS

Coatings are of primary importance in any system of corrosion protection and its protection efficiency is fundamental for the pipeline conservation in time. For buried mains or laid on the sea bed but in any case not easily inspectionable it is indispensable to have a protection with an expected duration at least equal to the foreseen service life of the pipeline (in the order of 50 years). In any case this does not apply to GRP pipelines since they are not subject to corrosion phenomena and if lack or scarce maintenance is planned for the pipeline the only material that can be recommended is GRP.

External coatings in bitumen

Bitumen coatings have been used in Europe for a long time. The production of this coating is declining due to new products. The relevant code is UNI ISO 5256; ECISS (European Committee for Iron and Steel Organisation) has drafted a similar project.

External coatings in hot polyethylene

This coating has had a remarkable development in Europe in the last 20 years in substitution of the bituminous ones. Relevant codes are UNI 9099 and UNI 10191, relative respectively to external extruded polyethylene coatings and through melting. ECISS has drafted 3 documents: external polyethylene coating extruded in 2 layers, 3 layers and through synthesis.

External epoxy coatings in powder

The use of this coating is not common and there is no code ; ECISS is preparing a code

External coatings of thermosetting resins

The production of coatings from liquid resins (epoxy, tar-epoxy, polyurethane, tar-polyurethane) is also scarcely used and generally applied with mobile equipment. There is no code but one is under preparation from ECISS for both polyurethanic and epoxy resins.

Internal bituminous protection

Internal bituminous protection is applied according to the following methods:

- bituminous coating; primer + bituminous mix (thickness 2-3 mm)
- Bitumen spray (thickness 50µm)

The relevant code is UNI ISO 5256. The production of internal bitumen coatings is slowly being abandoned. Bitumen coating is still used on small diameter pipes. This coatings can be easily removed by the water transported in the pipe with possible corrosion problems and water pollution.

Internal coating with cement mortar

This internal coating is produced in a single layer with thickness varying from 3 to 12 mm depending on the diameter. Cement mortar coating are designed for both non corrosive water (Portland and cooked) and corrosive water (with aluminium). There is a project of an European code EN 10298 Steel tube for pipelines – Internal lining with cement mortar.

The cement mortar coating is more competitive economical point of view due to the simplicity of the application technology (interior sand blasting is not required) and the low cost of the components.

Internal coating in epoxy resin

The coating is produced in thicknesses of 200÷400 µm independently from the diameter. There is only an American code.

Internal coating in polyamidic resin

The internal coating in polyamidic resin (thickness 250 µm) consists in a epoxy primer + a layer of polyamidic resin. There is no European code but ECISS is working on a project.

Comparison between different internal layers

Compared with resin coatings that only have a passive insulation action from the fluid to the pipe, cement coatings are more effective from the corrosion protection point of view because they have an active and passive action : the alkalinity of the mortar even in presence of micro cracks reacts with the limestone in the water and closes the cracks. On the other hand cement mortar linings are heavy and therefore storing, handling, transportation are in favour of epoxy coatings and also considering the possibility of failure of the cement lining itself due to this operations. Moreover cement lining slows down laying operations especially with big diameter pipes because of the weight.

CHARACTERISTICS OF THE MATERIALS

Mechanical characteristics

The table below summarises all main mechanical characteristics of all the alternative materials for the construction of large water mains.

Material Type	Yield Load R_s (N/mm ²)	Ultimate Tensile Load R_m (N/mm ²)	Percentage elongation A (‰)
Steel (Fe360-Fe510)	235-355	360-510	25-20
Ductile iron	300	400-420	7-10
PRFV	250	250	≥14

Regarding reinforced concrete pipes the mechanical characteristics are extremely variable in relation to the type

Anchoring

It is important to consider the possibility of leakage due to the soil movement and the consequent joint disassembly due to soil settling and also the effects of the internal pressure that generate on the pipeline longitudinal forces. These forces have to be countered with anchor blocks by vertices, branch offs, reductions and in the majority of cases where the pipeline is tested hydraulically, the need to anchor the pipeline is reduced or does not exist with the steel pipes since the continuity afforded by the welded joint makes them resistant to the longitudinal forces.

Corrosion resistance

Metallic pipes are subject to corrosion both chemical in the ground and from the transported fluid and also due to galvanic corrosion as opposed to GRP that is impervious to corrosion.

Corrosion control in steel pipes is made possible with internal and external coatings on the pipes in the factory and during installation and during the life of the pipeline with cathodic protection on the external surface. Cathodic protection requires continuous monitoring and in certain areas is even subject to theft. Ductile iron pipes in general are adequately protected from the cement mortar internal coating and from various external coatings related to the soil corrosiveness. In very aggressive environments DI pipes can be protected with insulating coatings and cathodic protection.

Steel reinforcements in concrete pipes have generally a good corrosion resistance being covered by a sufficient thickness of cement mortar but in aggressive environment it is better to protect them cathodically.

Resistance to Ageing

The only relevant analysis of the material behaviour is comparing the possible decay of their characteristics with time and with working pressure. For water mains the analysis can be restricted to pressure investigations as the temperature generally remains constant at around 20°C.

The behaviour of metallic materials, concrete and fiberglass are not influenced by the constant application of the pressure forces. Fiberglass is designed with higher safety factors to account for ageing (this is certainly a factor to consider when predicting the performance and duration of PVC and HDPE that display a thermoplastic behaviour namely decay of mechanical characteristic with time) but are all affected by pressure surges that can cause vacuum in the pipeline if it is not protected from it.

Hydraulic characteristics

Steel pipes in relation to the modern manufacturing methods have considerably smooth surfaces. The steel pipes with resin coating have an internal smoothness similar to that of fiberglass hydraulically speaking at least when new.

The ductile iron pipes, concrete pipes and the steel pipes with cement mortar lining have an absolute roughness greater than the fiberglass pipes and this is important in as much as higher head losses in gravity flow (siphons) or pumped pipelines. This has to be accounted for at the design stage.

Fiberglass has a polished internal surface and therefore a very low absolute roughness with benefits deriving from better flow, lower sedimentation and incrustation on the internal surface.

Installation

Reinforced concrete pipes are the heaviest and therefore the most difficult and expensive to handle. Pipes are up to 30 cm thick which means that they require an excavation 70 cm wider and probably one metre deeper since it requires a concrete foundation. In many cases this offsets the comparative cost advantage. Installation is slow in the order of 20-25 m/day. The service road along the line has to support very heavy equipment.

Steel pipes are supplied in random lengths of around 10 m depending on the diameter that determines the weight and therefore the weight limit of the site machinery. The progress is hindered by the welding process and therefore (apart from the high investment in welding equipment) also the continuity of the internal and of the external protection must be restored. Progress is 36m/day in average

Ductile iron pipes installation is simpler as it has a bell and spigot joint but is also expensive due to its weight. As in the above cases heavy equipment is required and progress can reach 50 m/day

Fiberglass is lighter to install, does not require any protection, fittings are prefabricated and installed without slowing down the installation, heavy equipment and service roads are not required and with light equipment progress can be in the order of 120 m/day

SELECTION CRITERIA

All the possible alternatives are up to the task of guaranteeing a long service life as the characteristics (or intrinsic defects) of each material are known and controlled by international codes and standards. All considered, fiberglass can be a cost-effective solution looking at high durability against any corrosion, smoothness of flow, simplicity of the engineering design and for ease and speed of installation.

From the required investment point of view, market conditions have proven so variable that it is not possible to make an estimate lasting over long periods and also the location not only of the project but also of the manufacturing plants (they may be thousands of miles apart) can alter any economical evaluation. Sometimes decisions for pipe materials are taken in designs a long time before the job being put up for tender. The final material choice should be taken case by case in a defined market situation just before the pipe is needed.