Stainless steel in potable water systems: the Italian experience

V. Boneschi, Centro Inox, Milano
A. Quazzo, SMAT S.p.A., Torino

1. Introduction

The purpose of this paper is to present the role of stainless steel as a material for use in potable water systems in Italy. By some years this is one of the emerging fields of application for stainless steel in Italy. As confirmed by recent applications (some of which are to be presented in brief at the end of this paper), stainless steel is gaining its own identity in an area where other materials nevertheless still dominate. For example a stainless steel tap is no more a new, while until 1997 it was only a possible thought.
In the second part of this paper will be presented a very efficient technique to install and restore big stainless steel tubes for the transport of drinking water. This technique, efficient and not invasive, has been already used, for example, in Torino to prevent the great loss in the old concrete aqueduct; it could be a lasting solution for all those aqueduct injured by the time.

2. Types of stainless steel used in the water cycle

The types of stainless steel most used to date in the water cycle are those of the austenitic chromium-nickel series, in particular AISI 304 and 304L (EN 1.4301 and 1.4306), or chromium-nickel-molybdenum, in particular AISI 316 and 316L (EN 1.4401 and 1.4404), in the formats which are readily available on the market. The table gives the chemical composition and main features of the most commonly used types:

	C	**Cr**	**Ni**	**Mo**
1.4301 (AISI 304)	≤ 0,07	17,00 ÷ 19,50	8,00 ÷ 10,50	-
1.4306 (AISI 304L)	≤ 0,030	18,00 ÷ 20,00	10,00 ÷ 12,00	-
1.4401 (AISI 316)	≤ 0,07	16,50 ÷ 18,50	10,00 ÷ 13,00	2,00 ÷ 2,50
1.4404 (AISI 316L)	≤ 0,030	16,50 ÷ 18,50	10,00 ÷ 13,00	2,00 ÷ 2,50

The choice of one or the other type depends on various factors, which must also be taken into account in order to find the right type of alloy according to the application. The basic parameters are:

- concentration of corrosive agents, in particular chlorine and fluorine ions;
- working temperature;
- velocity of the fluid on the walls of the material;
- surface finish;
- connection with other materials.

It should not be forgotten however that other factors also influence the triggering of corrosion; for example a careful design, which eliminates possible risks due to aggressive deposits will be an added guarantee of the efficiency of the system.

In any case stainless steel can definitely be adopted for components used in the individual stages of the integrated cycle of drinking water, unlike other materials, which have a highly specific area of application. This latter concept can be summed up briefly in a table:

	Stainless steel	**Other materials**
Collection	yes	cast iron, concrete, galvanised steel
Treatment	yes	galvanised steel, concrete
Storage	yes	concrete, galvanised steel, PE
Transport	yes	concrete, galvanised steel, cast iron, PE
End distribution	yes	copper, galvanised steel, PE
Domestic taps	yes	brass with chromium plating or with other types of plating

3. Resistance to corrosion

Stainless steel is normally chosen where there are particularly aggressive (corrosive) environments. Therefore availability is required of a material which ensures durability without, above all, the need for maintenance work, as may instead be the case for carbon steel or other coated alloys.

We have already mentioned some of the basic parameters for choosing the right type of alloy; we can now give a general summing up in a simple diagram of the decisive factors in the onset of corrosion:

for the material:
- chemical composition
- structure
- design of the part

- method of installation

for the corrosive agent:
- chemical composition
- concentration
- temperature
- relative velocity in relation to the material

When stainless steel is chosen, the type to be used has to be specified. At this point the main decisive factors are concentration of the corrosive agent (in particular chlorine and fluorine ions) and temperature.

As already mentioned, the stainless steel in the austenitic group, known as the 300 series, demonstrates the best behaviour against corrosion, in particular chromium-nickel-molybdenum alloy steel, due to a highly resistant passive film.
In order to minimise the onset of corrosion on stainless steel, precautions should also be taken during manufacture and installation.
First of all any form of contamination, for example ferrous, which could occur during storage or due to machining with tools previously used on carbon steel, should be avoided. Contaminated stainless steel is definitely more prone to corrosion.

Joints welded with filler material must be made with an electrode compatible with the base metal, while the connecting part of mechanical joints, for example bolts, must be in stainless steel or a material of the same quality (e.g. monel). In this way unfortunate instances of corrosion caused by galvanic coupling will be avoided.

Surfaces can be decontaminated by pickling products and inhibitors, appropriately measured and applied. For cleaning, detergents without a chlorine base can be used. In general soap and water or water with added soda will represent excellent products for cleaning stainless steel. Steam will also be an optimal sanitising product, again controlling the composition of the water base.

4. Hygiene, release, laws and standards

The hygiene of a material can in general be defined as the combination of a series of aspects which can be summed up as follows:

1. **Resistance to corrosion, in turn represented by:**

    - inertia in relation to substances with which the material comes into contact, so as to avoid release of its basic elements which alter the toxicological or taste and smell properties;

    - resistance to the action of detergents, solvents, sanitising substances and disinfectants, so as to enable actions for removing even the smallest traces of deposits, dirt and bacterial contamination;

2. lack of any type of protective coating which, when it splinters, gets worn or cracks or in any way deteriorates, creates surface gaps which are transformed into receptacles for germs and dirt. These gaps can become the location for the start of corrosion or lead to the uncovering of a base material which could be toxic;

3. compact surface without pores: the surface must not absorb particles of any origin, which subsequently alter the product with which they come into contact;

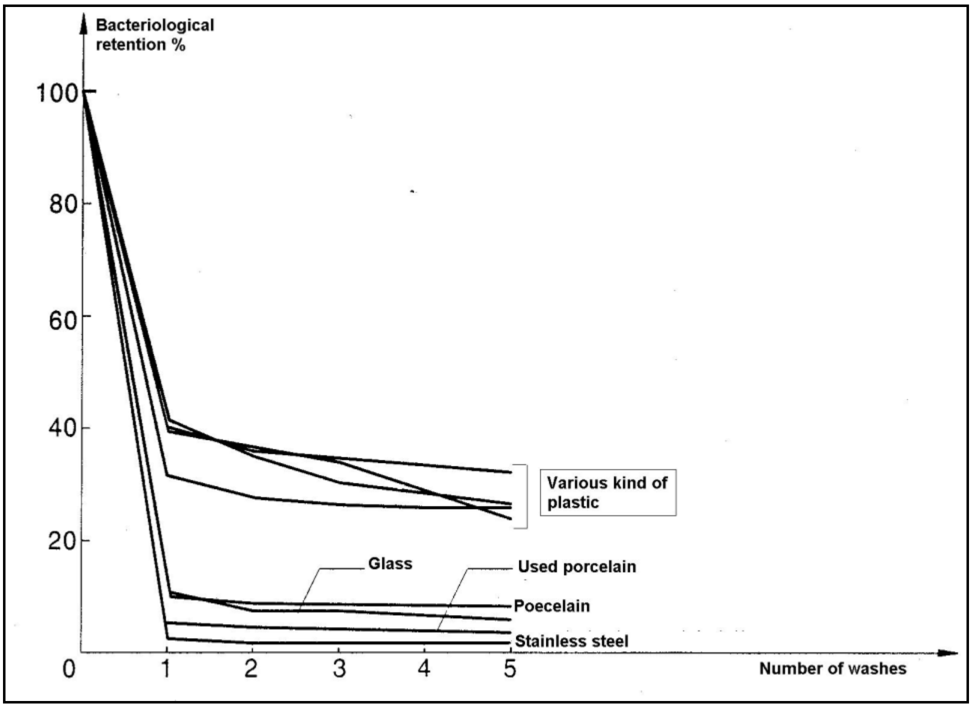
4. high resistance to impact and to mechanical stress in general: chipping and cracks would become fertile ground for germs;

5. resistance to thermal shock: during the cycle of use the sudden changes in temperature must not create breakage or cracks for the reasons already mentioned;

6. high bacteria removability: in the cycles of cleaning and sanitising of equipment and systems, whose surfaces are regularly contaminated by colonies of bacteria, it must be possible to restore all their original qualities. Bacteria removability must also be ensured throughout the life cycle;

7. low bacteria retention potential: removing bacteria is possible, although if they already have difficulties in forming, the conditions of use are improved.

All the types of stainless steel, varyingly combined, offer an excellent answer to all these requirements. For example the following illustration shows the trend in bacteria retention potential according to the number of washes for surfaces, in various types of material, used:



As confirmation of this fact, we should remember that there is a list of appropriate stainless steel types in the Decree of 21 March 1973, which lays down "Regulations on the hygiene of packaging, receptacles and tools intended to come into contact with substances for food use or with substances for personal use". This list numbers, with the relevant updates, around thirty types of stainless steel; definitely among those most commonly used are AISI 304 and 316 (EN 1.4301 and 1.4401).
The same decree states, under Art. 37, the limits of specific migration for the items in stainless steel intended for prolonged or brief contact with food substances. These limits are fixed on the basis of official tests and are in any case much higher than the actual values found in practice. The important thing is, rightly, the safeguarding of consumers.

Specific migration limits for trivalent Chromium and Nickel according to Ministerial Decree 21/31973	
Trivalent chromium (Cr III)	0.1 ppm
Nickel (Ni)	0.1 ppm

Decree Law no. 108 of 17 February 1992 has confirmed the suitability of stainless steel for coming into contact with food substances. This decree was issued to implement EC directives, which aim at standardising the specific laws of member states.
Again from the legislative standpoint, we should recall that both in Italy and the rest of Europe work is underway to draft documents relating to the materials, which come into contact with water for human consumption.
As regards the national document, stainless steel is to be included with reference to the approved list contained in the aforementioned Ministerial Decree of 21/3/73, while as regards the European document the various points dealt with and the methods of drafting the same are currently being defined.

Material suitable for contact with foodstuffs in Italy According to Ministerial Decree 21/3/1973	
Austenitics	202 – 301 – 302 – 303 – 303Se – 304 – 304L – 305 – 308 – 316 – 316 L – 316Ti – 316N - 321 – 347
Ferritics	430 – 430F
Martensitics	410 – 414 – 416 - 420 – 440
Duplex	329 – 329N – 2205 - 2304
PH	630

It should however be noted that other tests, performed in various laboratories, gave successful results. In the table below, has been made a collection of experiences:

Tests	
Test performer	**Test procedure**
Co-normative research	BS 7766:1994 and rig tests
DWI (Drinking Water Inspectorate)	BS 7766 modified
ITS (Interlek Testing Services)	BS 7766:2001
European Commission – Directorate-General for Research - Technical Steel Research "Assessment of stainless steels' compatibility in food and health applications regarding their passivation ability" – Contract No 7210-KB/422, 340 (1 July 1996 to 30 June 1999)	• Evaluation of the leaching rate in synthetic drinkable water with immersion test of one week at 23°c and 70°C; • Electrochemical study in the same water to plot the polarisation curves
LaQue Center for Corrosion Technology, Inc- "Hazard Classification of Alloys" – Prepared for the International Council on Metals and the Environment	Corrosion/leaching tests
British Steel plc, Swinden Technology – Avesta Sheffield Ltd ECSC contract 7210.MA/818	Leaching rig tests

Finally we would remind you of some of the existing standards (and draft) relating to use of stainless steel in the area of drinking water:

Standards and Regulations	Title
EN 10312	Welded stainless steel tubes for the conveyance of aqueous liquids including water for human consumption – Technical delivery conditions
DVGW W 541	Rohre aus nichtrostenden Stählen und Titan für die Trinkwasser-Installation; Anforderungen und Prüfungen
ANSI/NSF 61	Drinking water system components – Health effects
BS 4127	Light gauge stainless steel tubes, primarily for water applications
JIS G 3448	Light gauge stainless steel tubes for ordinary piping
DWI (Drinking Water Inspectorate) Application 56.4.477	Operational guidelines and code of practice for stainless steel products in drinking water supply.
Italian Ministerial Decree 21 March 1973, (it will be mentioned as reference document for stainless steel in the Ministerial Decree about materials in contact with potable water that is in an advanced stage)	Disciplina igienica degli imballaggi, recipienti, utensili, destinati a venire in contatto con le sostanze alimentari o con sostanze di uso personale.
French Decree 13 January 1976 (mentioned as reference document for stainless steel in the « Arrêté du 29 mai 1997 relatif aux matériaux et objets utilisés dans le installations fixes de production, de traitement et de distribution d'eau destinée à la consommation humaine - - Journal officiel du 1er juin 1997 »	Journal Officiel de la République Française – Matériaux au contact des denrées alimentaires – Edition mise à jour au 4 juin 1997 - Arrête du 13 Janvier 1976 relatif aux matériaux et objets en acier inoxydable au contact des denrées alimentaires (Journal officiel du 31 janvier 1976)
NF A 36-711 – Avril 2002	Aciers hors emballage – Aciers inoxydables destinés à entrer au contact des denrées, produits et boissons pour l'alimentation de l'homme et des animaux
Kiwa BRL-K762/02	Beoordelingsrichtlijn – voor het Kiwa-productcertificaat voor naadloze en gelaste roestvast stalen buizen voor waterinstallaties
NBR 14863	Reservatòrio de aço inoxidàvel para àgua potàvel

5. Recent examples of application in Italy

As proof of the increasingly growing interest in stainless steel by the sector of drinking water, we have included some recent examples of application.

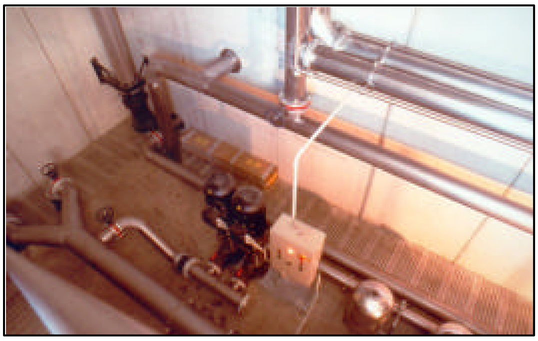
6. Taps

While the use of stainless steel for industrial taps has been widespread for some time now, it should be remembered that stainless steel has also appeared in the production of domestic types, for both bathrooms and kitchens. This is without doubt the real novelty: when visiting trade shows it is now possible to find more than one firm combining stainless steel taps with those made in traditional materials. The increasingly restrictive demands concerning quality of water have forced some producers to seek an alternative material to that traditionally used (chromium-plated brass). With stainless steel it is therefore possible to combine design needs with those arising from current laws. Another aspect found in the interviews is that relating to durability of properties. The cleaning cycles gradually wear down the coating of traditional taps, revealing the classic golden yellow colour of the material beneath. In large developments, such as hotels, a solution, which eliminates the aforesaid problem is therefore very welcome. The following are some models by different producers, which demonstrate the growing interest shown by this sector in stainless steel. Production starts with bar or pipe, cold worked and machined, but there are also examples of taps obtained by casting. In the graph below it is possible to see the growth in the number of Italian taps producer since 1997, when none offered on the market a stainless steel product:

7. Storage tanks: cladding of concrete tanks

In the building of tanks for drinking water there are two very important aspects: perfect water tightness and hygiene. For the first aspect in general, waterproof plaster or impermeable cement mortar is used as covering. the high roughness of the surfaces and the imperfect planarity which creates areas of accumulation.

The second aspect mentioned is a direct consequence of the first: the rough surface facilitates the proliferation of germs.
The solution adopted for the mountain town of Livigno (Sondrio), shown in the pictures here, proposes the use of precast concrete slabs already clad in stainless steel and welded on site. The sheet of stainless steel is an integral part of the formwork for the building of the panel: in this way perfect adherence of the materials and the lack of possible infiltration are guaranteed.
We should also underline the economic aspect of the solution which, in terms of life cycle cost over a lifespan of 50 years, enables costs to be halved compared to the classic solutions with concrete or epoxy cladding. Moreover emphasis should be placed on the fact that, given a cost of stainless steel cladding three times higher than the classic types, in percentage terms the increase in the total costs of the work was only 10%. Finally, mention of installation: speed, easy installation and transport of the sheets are in brief the outstanding features of the technology adopted.



8. Lake Como cave purification system

Expanding a Second World War air-raid shelter in order to hold a gigantic conditioning system capable of doubling previous capacity has represented a major leap forwards for Italian urban planning and systems engineering which to date had given us, underground, almost exclusively car parks and roads.

The tunnel, whose width varies between 15 and 20 metres and maximum height is 15 metres, has annual conditioning capacity of 16 million cubic metres (600 litres per second, compared to the 300 litres per second of the previous conditioning station) and required removal of 35 thousand cubic metres of earth, later reconverted for road maintenance.
When setting up the technological system, the use of EN 1.4301 (AISI 304) stainless steel for all piping and connectors, including flanges and bolts, and EN 1.4401 (AISI 316) for the lines conveying ozone and chemical additives was decisive.
The idea of using stainless steel came about above all when considering potential maintenance of the system. The metal parts in the cave are subject to the dew point and therefore the formation of condensation on their surface, which, on a traditional metal material, would require frequent surface protection treatments such as painting in order to prevent possible corrosion.
Moreover stainless steel does not release pollutants into the drinking water with which it comes into contact, not even if this is treated with ozone (oxidising agent for pipes), which is eliminated by subsequent filtering with sand and carbon.
The option chosen was found to be reliable and durable, as it will prevent water leaks and ward off emergency action with subsequent shutdown of the system and service disruption for users.

9. Water main rehabilitation: the stainless steel alternative

In an age of fiber optics, super fast computers, space missions to ascertain if there is subterranean water on Mars, the "terrestrial" water distribution system in large European cities, as well as in the United States, depends upon medium and large diameter piping laid so many years ago. We cannot and do not affirm that the admirable works of Roman aqueduct artisans do not guarantee even today, in certain cases, a supply of optimal potable water. It should nevertheless be said, that piping laid 70 if not 100 years ago, was not subject to vibrations from underground trains and neither could they foresee present-day vehicle traffic. Coated steel, asbestos cement, or gray iron piping, are the weak links in the distribution chain, especially in the historical centers of large cities, "untouchable" locations for the mass of problems involved with excavation in nerve centers caused by private and commercial urban traffic. Ancient networks which, consequently, suffer from leaks, infiltration into the soil, and in the worst situations, bursting mains with the consequent pits which may form in the road, presenting great dangers to traffic. Furthermore, pipe extraction constitutes a substantial cost and is, at the same time, a serious disposal problem (whenever asbestos cement is involved).

SMAT began a non-invasive experimental technique for the rehabilitation of its 2,800-kilometer network over 15 years ago. Many of the most sophisticated systems have been tried: from epoxy impregnated fabrics, to pre-formed plastic materials, pressure formed on site. In other cases, fiber glass liners were inserted into the old conduit by means of special cable-guided trolleys controlled by television camera; or also lengths of pipe were simply positioned head to head to be then joined together with an epoxy impregnated fabric sleeve. Another system experimented with was the use of normal sections of carbon-steel pipe, brought into position by special carriages and then circumferentially welded in the traditional manner. The pipe was next protected by the injection of bitumen into the air space between the old and the new conduit, and a low level of viscosity maintained by the flow of steam at 130°C fed through the new conduit, or also by epoxy-tar at 60°C. All of these technical solutions certainly do have innovative characteristics, but they do not fully measure up to expectations. In some cases, the process is too labor-intensive to be adopted on an industrial scale, in others, the reduction in section entailed with the insertion of bell and spigot joint piping produces non-acceptable results. Other solutions do not guarantee a reasonable degree of safety in terms of resistance at operating pressure (in certain parts of the city, this easily exceeds 8 – 10 atmospheres). The search for better materials and more appropriate methods for actually resolving the problem had to address several factors. Fist of all, the rehabilitation technique had be "trenchless". The laying work-site must be extremely contained and must extend longitudinally with respect to the axis of road in order to minimize the interference with traffic. The chosen material must be as "safe" as possible, resistant to high pressures, it must not undergo modifications with time, and it absolutely must not release substances into the water being transported (we know, in fact, of doubts nurtured by specialists in terms of endocrine modifiers). The system must also be advantageous from the economic point of view and must be simple, reliable, and reproducible so that ordinarily skilled welders can implement it.
Thus the TECHINOX® system was born, envisaging intubation of the conduits with stainless steel pipes.

In simple terms, this involves selecting the conduit to rehabilitate; taking it out of service; removing an appropriate sized length of the old conduit; positioning a simple stainless steel pipe into the vacant slot; pushing it into place; joining it to another with an automatic welding torch transported by an electronically guided trolley; and continuing to push and weld until reaching the arrival pit. The system is simple to understand, but in practice several hidden difficulties need to be overcome in order to achieve a reliable, reproducible, and transferable technology. During this delicate operation, SMAT had access to some of the of the most specialized organizations in the world such as the Turin Polytechnic, the Nickel Development Institute, the Centro Inox, the Breda Research Institute, and Alenia Aerospazio for welding technology, and Gilardoni S.p.A. for ultrasonic welding control.

10. Materials

AISI 304 stainless steel was selected as the rehabilitation material since it combines a series of advantages. First of all, it has been widely used since the beginning of the last century in the food industry where no contamination, yielding, or release of substances are allowed, and where the characteristics of the fluid being transported cannot be altered in any way whatsoever. AISI 304 stainless steel offers high resistance to corrosion due to its characteristic property of undergoing oxide passivation, i.e. the coating of its surface with an extremely fine oxide layer (for the most part chrome) with a thickness of about 1.6 – 4.0 nm with an extremely high protective capacity. Initially, four types of austenitic structure steel were taken into consideration and in particular X5 CrNi 18 10 (AISI 304) and X5 CrNiMo 17 12 (AISI 316) both in the standard version as well as in the low carbon steel L version. The composition's characteristics and the mechanical conformance of each material can be summarized by the following table.

Chemical composition of four austenitic steels

	Cr	C	Ni	Mn	Mo	Si	P	S
AISI 304	0.08	18-20	8-10.5	2.0		1.0	0.045	0.030
AISI 304L	0.03	18-20	8-12	2.0		1.0	0.045	0.030
AISI 316	0.08	16-18	10-14	2.0	2-3	1.0	0.045	0.030
AISI 316 L	0.03	16-18	10-14	2.0	2-3	1.0	0.045	0.030

L = low carbon steel

Mechanical characteristics of the four austenitic stainless steels

	R (MPa)	Rs(MPa)	A(%)	HR B
AISI 304	586	241	55	80
AISI 304L	517	193	55	79
AISI 316	620	276	50	79
AISI 316L	517	220	50	79

R =ultimate tensile strength; Rs =yield point; A =ultimate elongation; HR B= Grade B Rockwell hardness

By examining this data, it can be seen that these steels have extraordinary deformation characteristics attested to by the high value of ultimate elongation. This material plasticity is vital because of the sudden surges in pressure expected which can put the structural resistance of the entire construction to the test. As for corrosive behavior, it should be recognized that potable water has a *pH* greater than 4, a temperature always less than 25 °C, and that the piping under consideration operates in passive conditions and thus can be considered to be practically immune from generalized corrosion and to have a practically nonexistent corrosion rate. Since the presence of chlorides (even if at concentrations that do not usually exceed 0.2 mg/l) can cause crevice corrosion or pitting corrosion; corrosion effects have been studied for the four reference steels with seawater as the agent. Crevice and pitting corrosion results are given in the following table.

Localized corrosion rate in seawater

	Pitting corrosion g/(m^2 day)	Crevice Corrosion g/(m^2 day)
AISI 304	0.06	0.004
AISI 304L	0.06	0.004
AISI 316	0.046	0.002
AISI 316L	0.046	0.002

Even though seawater is much more aggressive than potable water due to its much higher concentration of dissolved chlorides, it can be seen how the rates of corrosion are clearly limited. Given that this rate is proportional to the concentration of Cl^- ions and having seen the very low concentration of chlorides (less than 0.2 mg/l), it can deduced that in our case the rate of corrosion turns out to be about 200 times less than the preceding one, and therefore negligible. With regards to the sensitivity phenomenon which can occur after welding operations, it has been observed that, since potable water does not favor the triggering of intercrystalline corrosion, this effect is also negligible. The Huey test was performed for all four of the chosen austenitic steels in order to evaluate their degree of sensibility; the results, after immersion in a boiling solution of 65% HNO_3 for a period of 48 hours, are reported in the following table.

Intercrystalline corrosion rate determined by the Huey test

	Corrosion rate mm/year
AISI 304	0.15 – 0.30
AISI 304L	0.15 - 0.30
AISI 316	0.23 – 0.33
AISI 316L	0.18 - 0.25

It should be noted that, given the elevated aggressiveness of the testing environment, the actual intercrystalline corrosion rate is much less. Therefore, considering the four steels analyzed, the use of the more precious classes was considered to be superfluous given that AISI 304 characteristics more than adequately fulfill service requirements. A parallel experiment was performed on ferritic steels such as AISI 430. Nonetheless, their characteristic property of superior sensibility for localized corrosion phenomenon favored the austenitic family.

11. Stainless steel pipe

A simple pipe is made from coils of hot laminated sheet steel, rolled, and longitudinally welded by continuous TIG (Tungsten Inert Gas) with welding material. Pipes are produced, brushed, and pressure tested in accordance with special SMAT specifications. The length of each sector is dictated by the coil height (on the average 60” tall); this dimension represents the minimum length. Whenever it is possible to use a launching pit of more generous dimensions, arrangements should be made to weld two or more elementary sectors in order to reduce the number of welds to be made later on site. Even eventual orbital welds between the various pipe lengths are performed with TIG technology and welding material. The structural calculation normally used to evaluate the sheet steel thickness to be used takes the form envisioned by UNI specification 6363 on hydraulic testing.

$$p=\frac{20\cdot s\ \cdot s}{D}$$

Where

" p " is the test pressure expressed in bar;

"σ" is the unit stress equal to 60 % of the yield point at 0.2 % proportionality. in N/mm^2 (as stated by UNI EN 10088 standard, - prospect III);

" s " is the nominal thickness of the pipe expressed in mm;

" D " is the external diameter of the pipe, also expressed in mm.

Experience has proved that for the normal use encountered in the European water supply sector, thicknesses of 2 to 3 millimeters have guaranteed a safety margin much greater than that required in practice. Furthermore, austenitic steel's exceptional plasticity characteristics should not be forgotten: pipe made from this material, thanks to this characteristic, is able to tolerate excesses in pressure. A typical case was that of a destructive experiment performed with a 750 mm diameter pipe with a wall thickness of 3-millimeters and that tolerated a 26-bar pressure without yielding; above this threshold, it showed minor signs of "plastic" yielding and it withstood pressure up to 28-bars when one of the welds joining the stainless steel pipe to the end "plates" failed. It should be noted that the weld which failed at 28 bars had been manually ground in order to attach a ring and, ... more importantly, the pipes selected for the experiment came from the same lot as pipes whose operating pressure in the tract concerned was 4 bars (which is less than 1/7 the yield pressure).

12. On-site welding

On-site welding is the crucial point of the process, where it is necessary to overcome three difficulties. The first is caused by the environment that may be narrow and may necessitate the use of portable equipment having minimal encumbrance; the second is due to the problematic coupling of pipes with reduced wall thickness and large diameters; the third is caused by the fact that, on site, it is necessary to rotate the welding torch around the pipe and not vice-versa as is done by piping manufacturers. While the cramped space of the working environment is difficult to avoid, the problem of pipe coupling has been solved in a simple and ingenious manner. A circular expander, which may be of circular section with independent pistons or else in the form of a band with only one piston, is placed within the pipes. This expander, made to the exact internal diameter of the stainless steel pipe, has a copper groove furnished with tiny holes through which Argon gas is fed to protect the reverse side of the weld. The string of distribution holes is positioned in exact correspondence with the point of union between the two pipe sections to be joined. The piston's hydraulic expansion ensures that the two edges of the tube are lined up perfectly and are kept together by the slight stretching of the material (the expander acts, in fact, as a reverse clamp). The expander, either single banded or multi-section, ensures uniform positioning of the pieces to be joined, and therefore helps ensure welding process consistency. Welding head motion is performed by two orbital carriages that translate on a rack positioned coaxially with the body of the pipe. These trolleys are electrically controlled and perform "stop and go" displacements, precise to the millimeter. The problem of being unable to move the piece while holding steady the position of the tool head is therefore not due to uncertainty and the inertia from motion, but from the force of gravity acting on the shape and the protuberance of the nugget according to its position in the pipe. The weld puddle will have the tendency to ooze towards the inside of the pipe while welding the upper section of the circumference, towards the outside when welding the lower portion, and in a series of intermediate directions when the torch passes along the sides of the circumference. The entire process study was focused on identifying the parameter combinations of intensity and duration of the impulse, duration of the weld puddle cooling pause, the quantity of weld metal and its relative entrance rate into the weld puddle, and into the spaces, and the traveling time of the heads between one impulse and the next. It should also be mentioned that, although steel experts are ready to swear the contrary, not all steels of the same type are identical; at times the “non-standard” titer of a single component can create enormous difficulties even for the most skilled welders. After years of experimenting, these parameters have been definitively determined according to the thickness and the diameter of the tube utilized, and they are part of the heart of the TECHINOX® system. The welding seam, now obtained totally automatically, displays a penetration of 100% and an absolutely satisfactory uniformity.

13. The work site

As previously mentioned, the laying pit has been designed to offer as little longitudinal encumbrance as possible. Vehicle traffic flow is, in fact, impeded minimally by solutions that run parallel to the axis of the road. According to the conduit location, a longitudinal work-site can cause relative restrictions to the width of traffic-lanes, but the disturbance caused is certainly more tolerable than any type of trench. The rehabilitation operation requires the creation of an underground work chamber straddling the old conduit and having a floor about 2’ below the lower rim of the conduit itself. These chambers can later become control chambers where flow meters and large valves are found. The standard chamber used for each operation on conduits with diameters up to 700 mm, is prefabricated and has internal dimensions of 7’ x8’. The chamber is then covered by a reinforced cement slab, perforated and furnished with one or two manholes; next, the wearing course of the road is restored on the roof of the chamber. The use of the prefabricated chamber is advisable for those cases in which the maximum operational speed is required, i.e. for excavations, positioning of the chamber, and restoration, in the least time possible (possibly even in one evening) to guarantee the least impact on traffic. In less “extreme” cases, it is possible to utilize the traditional open-air excavations, protected by adequate piles. The TECHINOX® work-site can attain dimensions smaller than 7 x 8’ or also, maintaining a face with width less than 7’, be lengthened as desired. More extreme configurations have been made in the center of Torino. A particularly demanding, 600-mm diameter gray iron tract located directly in front of the city’s main railroad station was, in fact, rehabilitated.
The main road runs parallel to the conduit, where three of the city’s most traffic-congested roads converge. If we consider this scenario, with the elevated flow of public vehicles from the central station, we can easily understand how the presence of a construction site (or worse yet, a trench) would give rise to intolerable bedlam or cause paralysis of traffic. Instead, with the assistance of underground work stations located at strategic points and with perforated manholes, it was possible to rehabilitate the entire tract without installing the work site on the road and without creating, therefore, any type of hindrance to the flow of traffic.

14. The thrust mechanism

The introduction of the new conduit into the old was performed by a correctly sized hydraulic piston.

This piston finds shelter in the old conduit (on the side opposite to that of the rehabilitation), and, opposing the old conduit itself, pushes the train of new pipes into position.

The piston, normally used for tracts up to one km in length and 170-mm in diameter, has a stroke of 1,700 mm and a thrust potential that can reach up to 30,000 kg. Stainless steel posses a good sliding friction index (further improved by the use of a special non-toxic grease that favors the sliding of the pipe train) and tracts of about one kilometer have been pushed without using the piston at its full potential. The piston rod rests upon a robust metal plate that guarantees the distribution of force onto the entire surface of contact with the pipe head and ensures that the thrusting maneuver does not create irregularities on the surface to be coupled with the next sector. Wherever operating conditions permit, and when pipe lengths greater than 1,500 millimeters can be used, a special positioning ramp is used which allows to position pipe sections up to six meters long without breaks. The ramp, positioned axially along the conduit, is made from a suitably sized skeleton of I-beams mounted within the excavation and jammed around the uncovered extremity of the tract to be rehabilitated. The piston group is not fixed, but composed of a base and a thrust plate joined by a piston with a stroke length of about 500 mm. The base plate anchors itself on special teeth, welded perpendicularly to the I-beams and enables the piston to move the front plate pushing the conduit pipe. When the piston retracts, the front plate remains joined with the laid pipe while the back base is moved ahead. Once the piston is completely withdrawn, the base plant anchors onto another series of thrust teeth. After each section of pipe has been completely introduced, the front plate is detached from the pipe, and the mechanism is made to move backwards manually. A new section of pipe is introduced and the welding cycle starts again. Whenever it is desired to perform the rehabilitation operation while maintaining the upstream and downstream conduit in operation, a special blank flange is used with a recess capable of containing the hydraulic piston, and a by-pass allowing flow to pass through a flying conduit, so to ensure a supply of water (even though reduced) during the rehabilitation process.

15. Longitudinal deviation and curves

The welding and pushing process thus appears simple enough: a break is made in the conduit, the pipe train is welded and pushed, the extremities are reconnected, and the new conduit can be put in operation: but what happens when the steel pipe encounters a curve or a longitudinal deviation?

It should be considered, furthermore, that curves, elbows, and displacements in parallel conduits almost always occur at intersections of roads, that is, in the most inconvenient place of all for installing an arrival work-site since it involves at least two lanes of traffic. In the past, one would tend to excavate above the curve in order to attain a double advantage: to insert tubes in two directions and, and when finished, to substitute the curve with a more appropriate special piece. This operating method creates, nonetheless, a series of drawbacks. First of all the location of the excavation is always crucial since, as already said, it is usually located at the intersection of two roads. Secondly, a thrust buttress is constructed ex novo as there is no conduit on which to anchor and place the hydraulic piston. This requires the construction of a bearing, usually in cement, for mounting the mechanism with consequential increase in the size of the excavation. The third drawback is given by the fact that, having to demolish the old elbow, the new curve, (generally a special piece built ad hoc) is not inserted into the conduit and is thus not protected like the rest of the new piping. The solution to this problem was to manually build the curve itself, with a slow and complex method.

Although this system is the only one available in certain situations, the “manual” solution is not optimal because it is difficult to protect the welding on the reverse side, and, an even greater problem, it can be only be used for diameters greater than 20” to allow a person to work inside. It should be said that, with this complicated and totally manual method, in the past years a good 250 meters of 600-mm diameter tract in one of the distribution nerve centers having a count of 10 45-degree curves (the zone is very rich in underground service lines). The challenge was to conceive and create a method that would make it possible:

a. to maintain the old curve and protect the new conduit;
b. to overcome the elbow to position a new work-site freeing it from the intersection;
c. operate at smaller diameters.

After many attempts, SMAT created an original pipe working system, patented obviously, which, combined with a special driving cylinder, enables the user to easily overcome curves up to 45 degrees. The pipe introduced is capable of deviating while always maintaining its section intact and without collapsing under the hydraulic piston thrust. The system for pushing at curves makes it possible to overcome axial and curved deviations ensuring the TECHINOX® technology great versatility of use even in the most problematic situations.

16. Structural hardening

In order to give the maximum structural resistance to the stainless steel pipe, ribbings of various sizes are placed on the tube at variable intervals and which, in addition to ensuring strength, are a valid first step to overcoming longitudinal deviations in the conduit.

16.1. An actual case.

A few months ago, on behalf of the Azienda Padova Servizi S.p.A.[1] (presently AMAG), SMAT performed a rehabilitation operation for 225 meters of Ø800 conduit in the very central Via delle Palme in Padova. At one extremity of the section involved, a work-site was made with sheet piles. The operators, using a motorized winch, lowered the pipes into the welding chamber and, by means of a positioning ramp made from a hydraulic piston with 500 mm long strokes, laid the new pipe, inserting it into the old conduit. AISI 304 hot-rolled stainless steel was used for construction, having a wall thickness of 3-mm, this was used since this size guarantees the greatest safety at pressures even 10 bars above operating pressure. The 3 meter long chosen pipes were formed by coupling elementary pipes 1,500 mm long (the width of the coil). Each elementary pipe was obtained by cutting to size, welding longitudinally, and flanging; the two elementary tubes to then be joined by circumferential welding, pressure tested, and washed. Field welds were made with the pulsed (Tungsten Inert Gas) method using welding rods and an orbital welding torch translated by an electronically controlled trolley. During the production phase, internal ribbings were made every 500 mm: these ribbings, in addition to stiffening the circumferential structure, enabled the pipe to overcome deformations in the longitudinal direction posed by the old conduit. The train of pipe, in fact, could easily pass through a sharp deviation of about 15° with respect the axis of the hosting conduit.

[1] [Azienda Padova Servizi = Padua Service Company]

The operation in Via delle Palme therefore confirms the superiority of stainless steel: it maintains its characteristics unaltered indefinitely, it does not burst, it is neither fragile nor tends to become fragile with time, it does not fissure, it tolerates settling of the soil (even seismic), and it does not release potentially toxic substances (unlike other less noble materials currently used in potable water conduit rehabilitation works).

17. Difference in diameter

Stainless steel piping introduced into the conduit obviously has a smaller diameter. The reduction in diameter is about 50-mm, both for small pipes like the 400 mm (into which a 350 mm pipe is inserted), as well as large (in the 1,000 mm conduit a 950 mm pipe is inserted). The use of greater reductions did not demonstrate any advantages in terms of sliding or ease of insertion.

In some cases the reduction in diameter was even less. In order to evaluate with precision the measure to be adopted, a deformable gauge is made to pass through the conduit. Having passed through, the gauge is read and the diameter is adopted taking into account the narrowest point. Sometimes a reduction of barely 20 or 30-mm is sufficient. The air-gap formed between the old and the new conduit is left empty for various reasons. First of all, in the eventuality of a leak, leaking water runs along the air gap and collects at the extremity of the tract: the leak is quickly identified without excavation and there is no dangerous infiltration along the length of the conduit. The air gap makes an excellent underground passage that can be exploited for eventual wiring (fiber optics, wide band, etc.). A further advantage of the empty air space is given by the fact that the external stresses are absorbed by the hosting conduit and do not minimally influence the stainless steel conduit. This characteristic is particularly valuable in proximity to vehicular crossings (trains, heavy transport) where sussultatory vibrations caused by passing vehicles is one of the concomitant causes generating the most common leaks. Contrary to common belief, rehabilitation conducted with stainless steel, if performed with TECHINOX® technology, does not entail substantially greater costs than methods that use less noble materials.
The new piping is made of precious and long-lasting material contributing considerably to the value of the water distribution system and to its reliability. The economic advantage is then very evident when modern Life Cycle Cost analysis is applied with parameters projecting 50 years into the future.

The choice of stainless steel material and of the TECHINOX® technology today represents the most rigorous and responsible decision for public administrations and management concerns desiring to ensure their city a long-lasting primary water distribution system of exceptional quality and reliability: today it is really possible to speak of a “stainless steel choice”.