STAINLESS STEEL PLUMBING

A GUIDE TO THE USE OF NICKEL-CONTAINING ALLOYS

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NICKEL-CONTAINING ALLOYS
Nº 11019

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This publication is concerned primarily with the UK plumbing and water industries; the tubing and fitting standards included reflect this. However, the general information is internationally relevant.

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INTRODUCTION

Today stainless steels are used more and more in potable water systems. Although stainless steel pipework and fittings have been available for many years - and used routinely in the chemical, pollution control, pharmaceutical and food industries - they are not so well known in water engineering and plumbing. But there are good reasons for stainless steel to be considered by those responsible for potable water supplies, particularly in large institutional and commercial buildings. This booklet provides some of the technical background for that decision.

Like any material, stainless steel has to be used in ways that are sympathetic to its special qualities. So this booklet also has guidance on the appropriate alloys to use, on achieving the best installation, and ensuring optimum service life.

The information in this booklet is tailored for designers, plumbers, end-users, maintenance engineers and others interested in providing reliable potable water systems. It covers:

- the nature of stainless steel
- corrosion resistance
- disinfection of stainless steel
- tubing standards
- fittings
- fabrication and handling.

A PLACE FOR STAINLESS STEEL

Since lead and galvanised steel fell from favour, copper and sometimes plastic have been the usual materials for piping potable water. But in many circumstances stainless steel will have advantages. These can be summarised.

- Stainless steel has very good corrosion resistance. This quality holds in the full range of potable waters, including soft waters, and is particularly valuable in large buildings.
- Stainless steel plumbing is particularly strong yet ductile.
- Stainless steel pipework is unaffected by high water flow rates.
- Stainless steel systems have low maintenance costs and other life-cycle costing advantages.
- Stainless steel pipework does not demand water treatment chemicals, other than for bacterial control.
- Stainless steel is non-toxic.
- Stainless steel is manufactured from a high proportion of recycled material and is itself 100% recyclable.
- It looks good.

Over the last two decades, the merits of using stainless steels in potable water systems have been clarified and enhanced:

- installation costs can be competitive
- a full range of joining methods and types of fitting have been developed
- stainless steel tubing is compatible with both stainless steel and copper base alloy fittings
- stainless steel tubing can readily be manipulated and welded.

As a result, stainless steel has established a successful track record in plumbing.

Davie and McCulloch

Stainless steel pipework in a hospital ceiling

WHAT IS STAINLESS STEEL?

All any iron alloy needs to be called a stainless steel is to have a chromium content of over 11%. So there are many different stainless steels with a wide range of corrosion resistance and mechanical properties. For water pipework, however, there are effectively only two main alloy families to consider - known commonly as 304 and 316. Grades within 316 are the more highly alloyed and have better resistance to aggressive waters.

These stainless steels are strong, ductile, do not embrittle at low temperatures, and are readily welded. Their high levels of corrosion resistance come from a thin, adherent surface oxide film which forms immediately in contact with air and is self healing if scratched. There is enough oxygen in piped waters to facilitate this healing and protective process. The alloys are resistant to soft and hard waters over the range of pH values specified by European and national directives. They can withstand water velocities of up to about 30m/s, so that erosion and turbulence effects are not a problem.

Because of their high corrosion resistance, there is no danger of corrosion products' contaminating drinking water supplies.

Table 1 Typical physical properties of pipe materials

	Specific gravity	Average coefficient of thermal expansion ($10^{-6}/^{o}C$) (0-100°C)	Thermal conductivity ($W/m^{o}C$) (100°C)	Specific heat ($J/kg^{o}C$) (0-100°C)	Electrical resistivity ($ohm\ mm^2/m$) Room temperature	Young's Modulus (kN/mm^2)	Magnetism
Stainless steel pipes	8.0	16	15	500	0.72	200	no
Carbon steel pipe	7.86	11.6	60	480	0.14	210	yes
Phosphorus deoxidised seamless copper pipe	8.96	17.6	340	390	0.02	110	no
Unplasticized polyvinylchloride pipe	1.43	70	0.05	1470	c. 10^{18}	-	no
Heat-resistant unplasticized polyvinylchloride pipe	1.56	70	0.05	1050	c. 10^{18}	-	no

THE PROPERTIES OF STAINLESS STEEL

Table 1 shows typical physical properties of stainless steels and other pipe materials. Stainless steel has a coefficient of thermal expansion and a specific heat similar to copper, less than one-twentieth its thermal conductivity, and a much higher electrical resistivity.

The mechanical properties of 304 and 316 grades of stainless steel are shown in **Table 2**. Stainless steel is much stronger than copper but retains good ductility. So it can be bent like copper, though requiring more force. The resulting pipework is stronger and more resistant to damage.

Table 2 Mechanical properties of stainless steels

Alloy family	EN 10088-2 Steel numbers	0.2% Proof strength N/mm^2 (min)	Tensile strength N/mm^2 (min)	Elongation %(min)
304	1.4301	230	540-750	45
	1.4306	220	520-670	45
316	1.4401	240	530-680	40
	1.4404	240	530-680	40
	1.4571	240	540-690	40

Values are for cold rolled strip in the solution annealed condition.
For compositions and equivalent standards, see Table 3 (page 6)

Stainless steel has excellent corrosion resistance in potable waters: its protective surface oxide film gives very low general corrosion rates and thus minimal metal pickup. It resists corrosion better than other metal pipes; this is maintained even at very high flow rates. Figure 1 charts the effect of water velocity on the corrosion of copper and stainless steel. This shows that stainless steel performs well at design velocities in excess of 2.5m/s. (As it can withstand water velocities up to 30m/s, it also has the ability to resist corrosion due to turbulence downstream of orifices, elbows, valves and pumps.)

This superior resistance means that localised breakdown of the protective surface film is very unlikely. Where chloride ions accumulate (tight crevices, stagnant water and under deposits), there is the potential for such breakdown. In practice, crevice corrosion and pitting of 304 grades of stainless steel are rare in natural waters containing up to 200ppm chlorides; 316 grades are equally rarely affected up to 1,000ppm chlorides. The maximum chloride concentration allowed in the UK is 400ppm, and the median concentration is in practice less than 30ppm. So both alloys are usually suitable. For high chloride waters and uncertain conditions, 316 grades should be used. (See page 6.)

In the chemical industry stress corrosion cracking (SCC) is associated with 304 and 316 grades at temperatures above 50°C when chlorides are allowed to concentrate on the surfaces. SCC is rare in hot water pipework, and the body of experience and information suggests that it is very unlikely in potable waters with chloride levels less than 250ppm at the temperatures experienced in domestic systems.

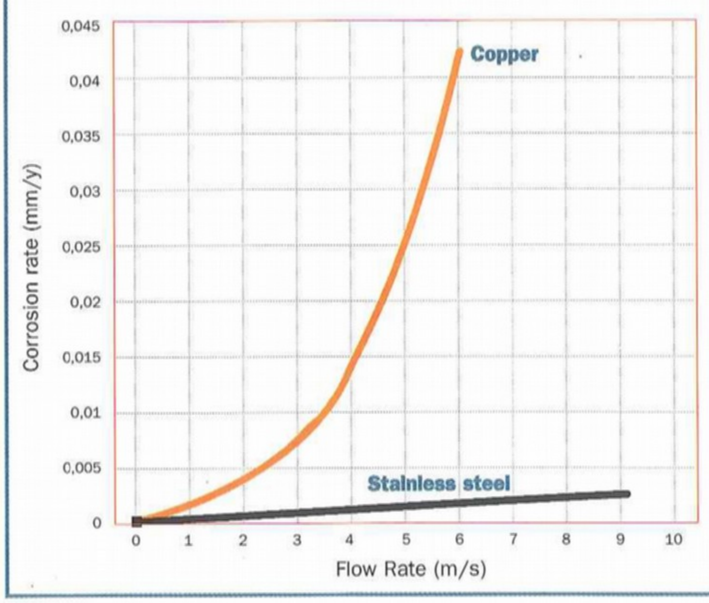
To preserve the *outside* of the pipework, chloride contamination should be minimised. For this reason, if insulation is needed, the material used with stainless steel should always have a low chloride level. Where insulation is exposed to external wet chlorides, it should be kept dry (eg plastic casing) or have a barrier (eg aluminium foil over 0.06mm thick with 50mm overlap) or coating between it and the stainless steel.

Stainless steel is galvanically more noble than steel, galvanised steel and cast iron: it should be electrically insulated from any such attachments to avoid corrosion of the less noble alloys. Stainless steels are slightly more noble than copper, but in practice copper based fittings have performed well in stainless steel pipe assemblies. Stainless steel or copper hot water cylinders can be used with stainless steel piping systems.

To ensure the best pipework performance, especially in large buildings:

- horizontal runs should have a fall
- dead legs should be designed out
- with high chloride waters, and as an added assurance against localised corrosion, 316 grades are better than 304
- low-chloride insulation (less than 0.05% water-soluble chloride ions) should be specified to avoid chlorides concentrating on outer tube surfaces
- if the outside of the insulation itself is likely to be exposed to wet chlorides (in coastal conditions, for example), it should be protected against chlorides' penetrating through to the pipe
- sealants and antigalling lubricants recommended for stainless steels (low-chloride) should be used
- if the pipework is hydrotested during commissioning, it should be drained promptly and completely afterwards.

Figure 1 Effect of water velocity on the corrosion of stainless steel and copper



DISINFECTION OF STAINLESS STEEL

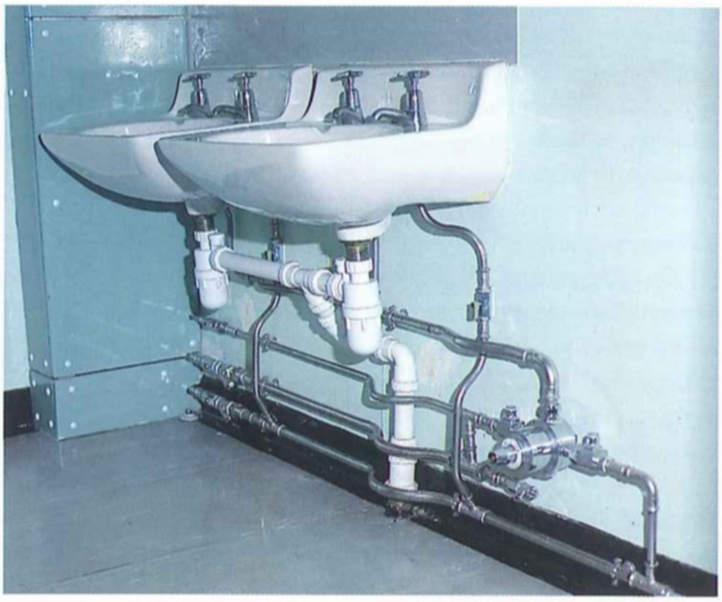
Chlorination is used to control the growth of bacteria and slimes. However, care has to be taken - just as with copper and mild steel pipes - not to increase the tendency for corrosion if particularly higher than normal levels of disinfection are maintained, eg in certain hospital systems.

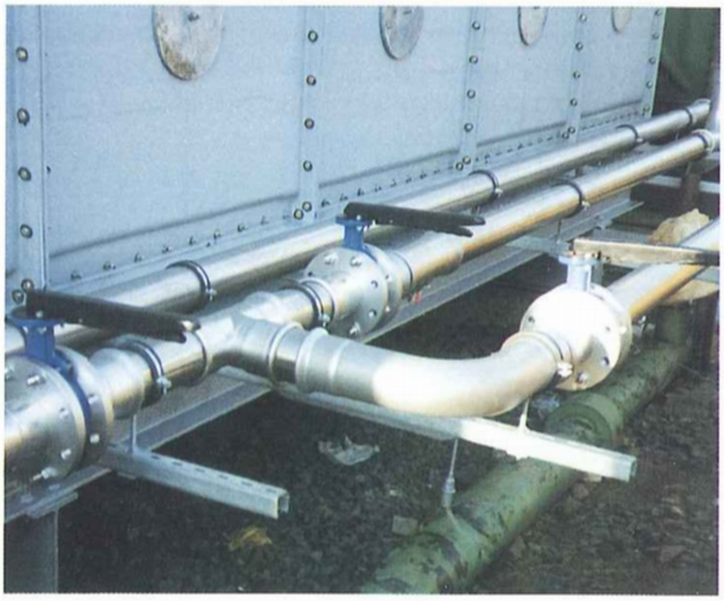
With stainless steels, the chlorine levels normal for mains water will not affect performance. If higher levels of chlorination are maintained for extended periods, the risk of crevice corrosion increases and 316 grades give better resistance. Even so, chlorine levels should be kept as low as possible and normal chlorine levels should be restored as soon as possible.

However, exposure to sterilising waters of even 25-50ppm free chlorine can be accommodated for up to 24 hours - as long as the system is flushed thoroughly afterwards.

Corrosion damage usually results from excessive or uncontrolled dosing levels; local build-up of concentrations within a circuit; and uncontrolled, extended cycle times. Where a system's operation risks such damage, alternative sterilising agents should be considered. Peracetic acid is required by the NHS in Scotland, Scottish Hospital Technical Note 2. (See page 6.)

Ozone treatment can be used in stainless steel water systems; in fact, 316 grades are used in the construction of ozone generators.





MEP Systems Ltd

Above: stainless steel bends and fittings under hospital sinks

Below: large diameter stainless steel feed from a cold water tank

Table 3 lists the current designations for specific variants of 304 and 316 grades of stainless steel and also provides their compositions in the current European standard for stainless steels, EN10088-2.

In systems where pipes or fittings are to incorporate welds, low carbon (<0.03%) L grades or titanium-stabilised grades will retain optimum corrosion resistance adjacent to the weld.

Where chloride levels in the water are over 200ppm, or there are tight crevices or deposits, or there is a higher risk of chloride contamination on the outer pipe surface, the higher molybdenum grades (Types 316, 316L and 316Ti) are preferred to avoid localised corrosion. In Germany, where the use of stainless steel is more established, Type 316 grades have performed excellently in all waters, hot and cold, with chloride contents up to 250ppm.

Warning There is a free machining grade of stainless (Type 303, 1.4305) which contains a high sulphur level to encourage the formation of manganese sulphide stringers in the alloy and thus make it easier to machine. This can be subject to preferential pitting in water systems and is not recommended for exposure to potable waters.

Table 3 Stainless steels commonly used for potable water service

EN10088-2 Steel no.	Composition Wt%					Nearest equivalent grades in	
	C	Cr	Ni	Mo	Ti	AISI (UNS-S)	BS*
1.4301	0.07 max	17.0-19.5	8.0-10.5			304 (30400)	304S31 304S15
1.4306	0.030 max	18.0-20.0	10.0-12.0			304L (30403)	304S11
1.4401	0.07 max	16.5 -18.5	10.0-13.0	2.0 -2.5		316 (31600)	316S31
1.4404	0.030 max	16.5 -18.5	10.0 -13.0	2.0 -2.5		316L (31603)	316S11
1.4571	0.08 max	16.5 -18.5	10.5 -13.5	2.0 -2.5	5xC to 0.70	316Ti (31635)	320S31

*Now replaced by BS EN 10088-2
(During 1995, the designation number, name, composition range and specified mechanical properties of EN 10088 officially replaced any national designation and standard for a similar stainless steel in countries throughout the EC)

TUBING STANDARDS

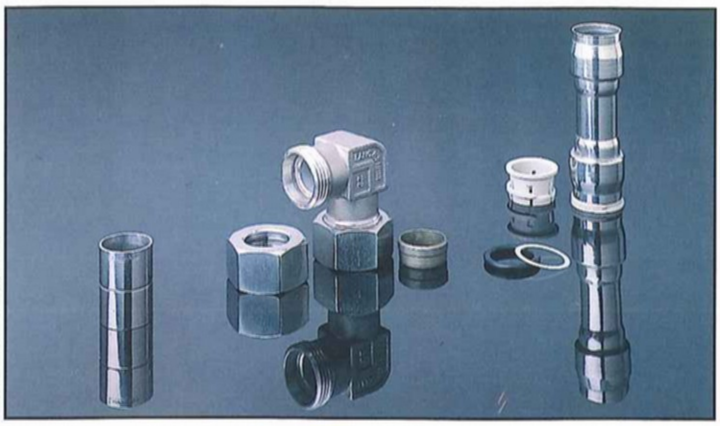
BS 4127:1994 Light-gauge stainless steel tubes, primarily for water applications. This specifies 304 and 316 grades of longitudinally welded tubing in the as-welded or annealed condition from 6mm up to 159mm diameter.

BS3605:1991 Austenitic stainless steel pipes and tubes for pressure purposes. This covers a range of 304 and 316-type compositions in seamless (part 1) or welded (part 2) pipes and tubes in various conditions.

BS 4127 & BS 3605 are the more frequently used standards for potable water systems; BS 3605 is the more stringent specification and preferred for the most exacting applications. As for wall thickness for each size, BS 3605 is thicker and approximates to the German Standard, DIN 2463.

The National Health Service in Scotland has issued guidelines as Scottish Hospital Technical Note 2, Domestic Hot and Cold Water Systems for Scottish Health Care Premises (from the Stationery Office) which includes a specification for the use of low-carbon, Type 316L stainless steel.

There are two other stainless steel tubing standards that are associated with industries handling liquids for human consumption: BS 4064 Stainless Steel Tubes for Dairy Industry Applications and BS 4065 Stainless Steel Tubes for Food Industry Applications. These relate to tube made by seam welding and subsequently 'calibrated' - ie bead rolled or bead hammered to improve roundness and internal surface finish.



Lancashire Fittings Ltd

Above: from left to right, capillary, compression and push-in fittings

Mannesmann Pressfitting

Right: tubing, assembly tool and pressfittings

FITTINGS

A variety of stainless steel fittings are available:

- capillary fittings for silver soldered and adhesive bonded joints
- compression fittings
- pressfittings
- push-in fittings.

BS 4127 is designed to be joined by capillary and compression fittings. Stainless steel tubes are galvanically compatible with copper alloys in potable water and so copper-based alloy compression and press fittings can be used. These are normally made from dezincification-resistant brass or gun metal.

Capillary In the late 1960s, copper capillary fittings gave stainless steel systems a poor reputation because chloride-based fluxes used in soft soldered joints caused serious pitting problems. The availability of stainless steel capillary fittings in the early 1970s, and the use of phosphoric acid fluxes, solved this problem. Chloride fluxes must never be used. Lead base soft solders are no longer allowed for potable water systems; *silver base solders*, with the appropriate non-chloride fluxes, are used. Knife-line and interfacial corrosion have occasionally been found at soldered or brazed joints; a recommended optimised solder should be specified by the fitting suppliers. *Adhesive bonded fittings* are approved for water systems up to 80°C by the UK Water Byelaws Scheme (WBS), managed by WRc. Adhesive bonding is usually suitable for waters only within pH 6.5-8.5.

Compression Stainless steel compression fittings to BS 4368: Part 3: 1974 and DIN 2353: 1991 are available. (The latter is likely to form the basis of a European standard.) Alternatively, compatible copper alloy compression fittings can join stainless steel tubes to BS4127 and BS3605. With aggressive water, a dezincification-resistant range is recommended.

Pressfittings are applied by an electro-mechanical tool. Sound, leak-proof joints can be made in seconds by crimping the fitting around a polymeric seal ring. These systems have become well established over the last decade in Germany and the UK; they use a heavier walled tube than BS 4127. Stainless pressfittings are available up to 100mm nominal diameter; the tubes and fittings are available in 316 grades of stainless steel and are WBS listed.

Push-in In 1996 a design of push-in fittings was introduced. They have WRc approval and are WBS listed. They are used with tube which has been given a special surface treatment and is heavier walled than BS 4127. Joined in two seconds, the joints are sealed using an EPDM elastomer O ring. A plastic collet provides gripping strength.

If *flanged joints* are used, care should be taken to select a suitable gasket material. Combined crevice and galvanic corrosion has been found in the chemical industry where the packing material contained graphite or chlorides. The problem is avoided by using suitable polymeric gaskets or packing.

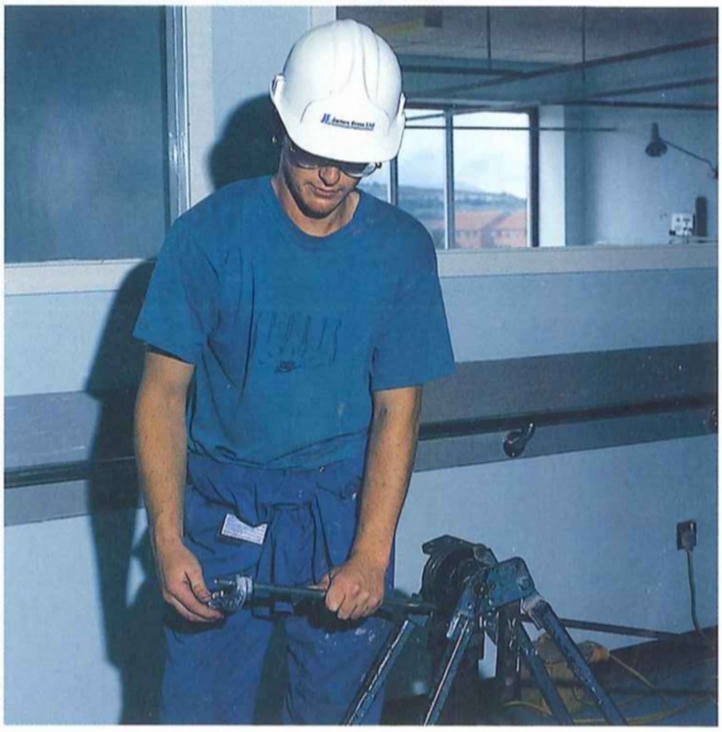
Longitudinally welded tubing is generally used for water service. Although ductile and easily fabricated, stainless steel tubes are stronger than copper tubes and require tooling of a higher load capacity for bending.

Stainless steel tubing can be easily cut by hand pipe cutters, saw or rotary abrasive cutter. High-speed tools and carbide blades should be used to ensure clean, square-cut or bevelled faces.

Standard machines for bending copper tubing are acceptable for stainless steel - but should be in steel and strong enough to bend at least the next size up of copper. For tubing sizes above 28mm, a ratchet or hydraulic machine should be used. Sizes below 15mm can be bent with a small bending machine using a mandrel and former, or an internal spring.

Stainless steels can be readily welded - with cleanliness the watchword for realising the full potential of the material. TIG methods are preferred, using an argon shield gas. It is important that welds penetrate fully, with smooth inside diameter weld roots, so as not to provide potential sites for deposits, or for the accumulation of chlorides which might cause corrosion. Inert gas back purging is also necessary during welding to minimise heat tint.

Stainless steel pipework can be connected to an existing copper system by a stainless or appropriate copper base compression fitting. Alternatively, adapters are available for the pressfitting system.



Stainless steel tubing is bent in the usual way

For optimum performance from stainless steel, good workshop practices are paramount. The golden rules are:

- ensure the piping is kept clean and free from damage during storage
- ensure weld areas are clean and free from all types of contamination (grease, crayon markings, etc) prior to welding
- establish consistent weld procedures
- provide full-penetration welds
- use protective, inert gas purging for the back of welds
- pickle the joint by immersion if possible, or clean locally using a suitable pickling paste, or a mechanical method
- after cleaning, use secure end closures that will stay in place until final erection.

Fixing Stainless steel pipework requires the same fixing support as other materials. This includes suspension fixtures, hangers, vertical pipe support fixtures and other anchoring devices. Unless the hangers and pipe supports are made of stainless steel, they should be insulated to prevent metal-to-metal contact, with the attendant possibility of galvanic corrosion in damp ambient atmospheres. Plastic or rubber mechanisms are an alternative.