Review paper
UDC 664.03:669.14.018.8

MATERIALS OF CONSTRUCTION – THE ROLE OF STAINLESS STEELS

Eric Partington[1*]

[1]Nickel Institute, Well Croft, Ampney St. Mary, Gloucestershire, GL7 5SN, United Kingdom

***e-mail: eric@effex.co.uk**

Abstract

An understanding of how relevant materials may behave in a food-processing environment - whether they are metallic, elastomeric, plastic, and composite or glass - is essential to their correct selection as materials of construction. Only by matching the choice of material to the working environment (and that includes not only the food being processed but also the cleaning processes applied to the equipment) can the safety, hygiene and life-time economics all be optimised. This paper will examine the sources of advice available to help the engineer make these critical decisions. Stainless steels are frequently seen as the materials of choice in such applications, and the properties of this versatile family of strong, corrosion-resistant, easily-fabricated and, ultimately, recyclable materials will be discussed.

Key words: *Materials, selection, construction, operating environment, stainless steels.*

1. Introduction

An engineer may appreciate that metals generally lose some strength at sufficiently high temperatures, but does he know which elastomers become harder as they are heated and which ones become softer? A synthetics expert may know that certain plastics become brittle at low temperatures, but does he appreciate that some common engineering metals do exactly the same thing?

Can either of them afford to get it wrong - to under-specify and discover that, although they were less expensive, the materials they selected did not perform satisfactorily, or to over-specify and incur unnecessary costs? If not, where do they look for help?

One answer is EHEDG's Document No. 32 [1]. This Guideline was written primarily for designers of food-processing equipment to help them understand something of how a range of engineering materials, from synthetics to stainless steels, may behave under the conditions which they will meet in service. But it should also help the purchaser of such equipment to appreciate the capabilities and the limitations of those materials, and therefore help him to specify the equipment he wants more skilfully and cost-effectively.

2. Materials

Document 32 [1], covers a wide range of materials including composites, ceramics and glasses, but we will look briefly at how it describes the behaviour of the three main groups of materials used in the construction of food-processing equipment - elastomers, plastics and metals.

2.1 Elastomers

Elastomers are highly elastic and readily return to their original shape once removed from a source of stress. For this reason they are often considered the best material for seals, gaskets and hoses.

An elastomer is composed of a number of ingredients including polymers, fillers and plasticisers. However, according to their formulation and how they are mixed, two compounds of a similar type and hardness may have significantly different physical and chemical properties such as temperature resistance or chemical compatibility. It is therefore important that the user adequately specifies the application so that both the purchaser and the manufacturer of a product understand and agree the environment in which it is to operate.

Document 32 [1], suggests that, together, they consider swelling and shrinkage caused by temperature (and other) changes and also Compression Set, and their combined effect on the design of seals. And the possibility of high temperatures causing seal materials to adhere to the surfaces of their housing. Then there are useful tables in the Guideline which indicate in which operating environments each type of material performs well or performs badly.

2.2. Plastics

This document looks at plastics in much the same way but, of course, plastics are quite different materials from elastomers.

The term 'plastic' is applied to a wide range of synthetic polymers, but whilst metals are made to standard specifications by a number of producers, plastics are generally made to the supplier's own specification. Each plastics manufacturer is likely to supply different grades of what, at first sight, appears to be a standard material but which differ in their tolerance of temperature, stress, cleaning agents, strong halides such as brines, fats and oils.

And some plastics can be sensitive to pH. Poly Vinylidene Fluoride performs well in strongly acid environments, and Poly Ether Ether Ketone in strongly alkali environments - but not the other way round ... Or ultra-violet radiation, causing embrittlement; or hydrolytic attack, leading to cracking or mechanical failure; or electrostatic charges when rubbed, such that they attract dust and bacteria; or phase changes at specific, critical temperatures, below and above which they exhibit markedly different properties; or creep, and therefore slow dimensional changes, even under low stresses; or shattering under impact, possibly releasing sharp particles that are not detected by common in-line metal detectors. And surface abrasion can increase the accumulation of soils and biofilms and reduce cleanability.

2.3 Metals

Section 4 of the Guideline [1], looks at metallic materials in a similar way, considering general corrosion, as can be suffered by aluminium, copper and painted carbon steels.

Bringing different metals into contact under an electrolyte such as a salty food or beverage can create a galvanic cell like an electrical battery and can cause one of the metals to be corroded far faster than it would have been by the food or beverage alone.

When designing against stresses it is important to allow not only for static but also dynamic stresses such as those due to pressure fluctuations and to appreciate the significance of cyclic stresses, such as may be set up by vibration.

As with many phenomena which may not initially be familiar to the engineer, Document 32 does include a glossary of over 50 technical terms. Note that for each possible behaviour the Guideline recommends a procedure for assessing a material's performance. Four Appendices together list over 150 ASTM [2], ISO [3], DIN [4] and CEN [5] tests.

The effect of the sudden application of a force to a metal can be much more damaging than if the same force is applied slowly. Friction can result in significant wear, and erosion and cavitation inside pipework can cause extensive damage. And castings can exhibit surface-breaking pores which may be a hygiene hazard.

2.3.1 Stainless steels

As common as it is today steel, as a practical construction material, was only developed in the year 1860. And less than 50 years after the very first steel came the development of the most versatile of its variants – stainless steel. Long ago stainless steels established themselves as the materials of choice for the construction of almost all food-processing and storage equipment. But why? What are the attributes which make stainless steels so suitable for food preparation? Well, essentially, their performance in all the respects discussed above. But what is stainless steel?

Just as 'steel' is iron which contains a controlled amount of carbon, so a 'stainless steel' is steel which contains a controlled amount of chromium. However, 'stainless steel' is not a single material but a family of over 200 iron-carbon-chromium alloys, although only about twenty are commonly used in food preparation.

Stainless steels are steels which contain a maximum of 1·2% carbon and a minimum of 10·5% chromium and it is this chromium content which is the primary source of their corrosion resistance. It comes from an invisible, protective film of chromium-rich oxide which forms spontaneously on their surfaces in the presence of oxygen. Even if it is physically or chemically damaged, this film will very rapidly repair itself once the source of the damage is removed and the surface is exposed to oxygen again.

It is the dependability of this corrosion resistance which is the primary reason for the widespread use of stainless steels in food preparation equipment. If there is no measurable chemical reaction between the stainless steel and the food, the food will remain free from metallic contamination or corrosion products and there will be no corrosion damage to the material such as pits or cracks which could weaken its structure or, just as importantly, in which organisms could hide and multiply.

But stainless steels are also tolerant of the wide range of temperatures frequently encountered in the production of foods, from cooking to freezing, and they resist thermal shock - a rapid and significant change of temperature - very well. The physical properties of some stainless steels make it easy to form them into the smooth shapes necessary if the food processing equipment is to be easily cleaned and they are readily welded. They are strong and they resist impact, fatigue, wear, abrasion and erosion.

Of course not every grade of steel with more than 10·5% chromium will resist staining in every operating environment. If the operating conditions are particularly aggressive some grades of stainless steel may suffer one or more forms of corrosion.

Chlorides are the enemy of many stainless steels which is why it is so important for designers to understand the chemistry of the operating environment - not only of the particular food to be processed but also of the cleaning agents which will be used, as some of these can be high in chlorides.

Chlorides can cause localised pitting of stainless steel, higher temperatures accelerating the attack. The answer may be to use a chloride-resistant grade of stainless steel such as duplex steel and this will be discussed a little more later on. This published diagram shows the conditions which may necessitate their use.

Together, good design and an understanding of the way materials can behave will have a major influence on the performance and life of a piece of equipment. For instance, corrosion can be accelerated in fine crevices such as are often associated with gaskets and seals or areas of metal-to-metal contact.

In areas where chlorides, temperatures and tensile stresses are all high, a form of corrosion known as stress-corrosion cracking can occur. When subjected to high levels of chlorides at an elevated temperature, the stainless steel exhibits the characteristic branching pattern of stress-corrosion cracking - and this is what can happen inside your equipment if the correct materials are not used.

2.3.2 The stainless steel family

There is, however, an extensive family of stainless steels from which the one most suitable for almost any environment can be selected. The 'simplest' stainless steels are the iron-carbon-chromium alloys and these fall into two groups.

The first group is the 'martensitic' stainless steels. These contain only about 13% chromium (and so they are the least expensive stainless steels) but they have high levels of carbon (even up to 1%). Whilst this high level of carbon makes them difficult to form and to weld, it also makes them very hard and strong. They are ideal where the environment is not particularly aggressive, but where resistance to wear is important such as knife blades and the wearing parts of pumps.

The other iron-carbon-chromium group is known as the 'ferritic' stainless steels and these will typically contain about 17% chromium and about 0·05% carbon. They are commonly used for household appliances such as dishwashers, refrigerators and pans. They have acceptable corrosion resistance and are relatively inexpensive.

The addition of nickel to stainless steel improves formability, weldability and corrosion resistance, and there are three groups of the iron-carbon-chromium-nickel stainless steels. The first group is known as the 'austenitic' stainless steels. An 8 to 10% nickel content makes them easy to form and yet tough and their 18% chromium gives them an excellent resistance to corrosion. They are the most commonly-used stainless steels in the food and beverage industries. Grade 1.4301 (AISI 304) is an austenitic stainless steel which contains approximately 0·05% carbon, 18% chromium and a minimum of 8% nickel. It is used in a wide range of applications from brewing vessels to kitchen sinks to table cutlery to milk tankers.

The addition of molybdenum to this austenitic stainless steel further improves its resistance to pitting corrosion. Grade 1.4401 (AISI 316) is AISI 304 with about 2% molybdenum added and a little more nickel and it is particularly resistant to high levels of chloride or sulphur dioxide, making it suitable for the storage of white wines, salty foods and aggressive media such as the pectin used in jam-making.

One of the second group of iron-carbon-chromium-nickel stainless steels - the 'duplex' steels - may be required in very corrosive environments such as mustard- and vinegar-making, cheese dairies or fish-canning plants. These steels have very high levels of chromium - perhaps 22% - possibly as well as about 3% molybdenum. Most duplex steels are, of course, more expensive than the austenitics.

The costs of the third group of iron-carbon-chromium-nickel stainless steels are high because of their material contents but the 'precipitation-hardening' stainless steels combine the good corrosion resistance of the austenitic grades with the excellent mechanical properties of the martensitic steels.

The reliability and longevity of all these stainless steels contribute significantly to their favourable Life-Cycle Costs. Even when a piece of stainless steel equipment has reached the end of its useful life, the stainless steel itself hasn't. Today, a newly-manufactured stainless steel object will have an average recycled content of about 60%.

And, of course, a feature particularly important when presenting food either in the retail outlet or in the domestic environment is that stainless steels are pleasing in appearance.

So there really is an elastomer, a plastic or a stainless steel for almost every application. But how do we find out which is the right one for the job?

3. Conclusions

- Document 32 suggests that the starting-point must be the user defining the operating environment - not only which of the food he will be processing but also of the chemical processes he intends to uses to clean his equipment. Then comes technical collaboration between the user and the potential supplier. Together, they can benefit from their combined experience of the past performances of candidate materials and take advantage of all the expertise and advice out available from, for instance, their material suppliers, the Nickel Institute and Euro Inox. These and many more sources of technical information are all listed in Document 32, together with over 30 references (including both technical papers and the latest food-orientated legislation.
- The primary objective of this document is to offer practical guidance on how materials behave and how they may be selected and used as effectively and economically as possible. I think you will find it a very useful Guideline.

4. References

[1] EHEDG's Document No. 32. *Materials of construction for equipment in contact with food*. European Hygienic and Engineering and Design Group International Secretariat, Frankfurt/Main, Germany.

[2] ASTM International. *ASTM test procedures.* <URL: http://www.astm.org/. Accessed 5 July 2011.

[3] ISO. *ISO test procedures*. <URL: http://www.iso.org/iso/home.html. Accessed 6 July 2011.

[4] DIN. DIN test procedures. <URL: http://www.din.de/cmd?level=tpl-home&languageid=en/. Accessed 6 July 2011.

[5] CEN. CEN test procedures. <URL: ttp://www.cen.eu/cen/Services/ConformityAssessment/Certification/Keymark/Pages/Productsandstandards.aspx/. Accessed 6 July 2011.