STAINLESS STEEL INFORMATION SERIES

sassda®
southern africa stainless steel
development association

STAINLESS STEELS & ALLOYS AT HIGH TEMPERATURES

Stainless steels are generally used for their corrosion resistance. However, due to their chromium (Cr) and nickel (Ni) contents they have a broad range of useful high temperature properties and are therefore used in many high temperature applications.

For a material to give useful service at high temperatures the two major factors to consider are:

1. Its mechanical properties and
2. Its ability to withstand the environment at such high temperatures.

High temperatures are not exactly defined, but may be taken as the temperatures at which the effect on mechanical properties and/or attack by the environment becomes significant. For stainless steels and stainless alloys this will normally involve service at high temperatures above 500°-550°C.

However, it is not possible to consider only the conventional stainless steels because the varying conditions and severity of high temperature service will often require properties that the stainless steels do not possess. This necessitates the use of additional alloys, broadly termed the stainless alloys, which are typified by having:

- A higher alloy content (ie Fe < 50%).
- A nickel content greater than chromium (ie %Ni > %Cr).
- Further extend to the nickel based alloys (ie Ni > 50%).

Table 1 gives the typical compositions of some of the stainless steels and stainless alloys commonly used in industry.

High temperatures cause significant reduction in both the tensile and yield strengths compared to those at ambient temperature.

TABLE 1: The nominal compositions of wrought and cast stainless steels and stainless alloys used in high temperature service

MATERIALS	COMPOSITION				
	C%	Cr%	Ni%	Fe%	Other %
STAINLESS STEELS					
FeCr Wrought (17Cr)	0,08	16-18	-	≈80	
(25Cr)	0,20	23-27	-	≈73	
(17Cr Ti Nb)	0.05	16-18		≈80	Ti, Nb
Cast (28Cr)	0,50	26-30	4,0	≈70	
FeCrNi Wrought (18Cr8Ni)	0,08	18-20	8-12	≈68	
(18Cr10Ni Ti)	0,08	17-19	9-12	≈68	Ti 5 x % C min
(21Cr11NiNSiCe)	0.09	21-23	10-12	≈66	N-0.15, Si 1.3, Ce
(23Cr14Ni)	0,20	22-24	12-15	≈60	
(25Cr20Ni)	0,25	24-26	19-22	≈55	
Cast (25Cr12Ni)	0,2-0,5	24-28	11-14	≈60	
(26Cr20Ni)	0,2-0,6	24-28	18-22	≈52	
STAINLESS ALLOYS					
FeNiCr Wrought (37Ni18Cr)	0,15	18	37	≈45	
(32Ni21Cr)	0,10	21	32	≈46	Al0,5 Ti0,5
(20Ni22Cr Co Mo W)	0,10	22	20	≈33	Co18 Mo3 W2,5
Cast (35Ni26Cr)	0,35-0,75	24-28	33-37	≈39	
(35Ni17Cr)	0,35-0,75	15-19	33-37	≈48	
(40Ni20Cr)	0,35-0,75	17-21	37-41	≈42	
NiCrFe Wrought (76Ni16Cr)	0,15	16	76	≈6	
(61Ni22Cr)	0,10	22	61	≈14	Al 1,5
(47Ni22Cr Mo Co W)	0,10	22	47	≈18	Mo9 Co2 W1
Cast (60Ni12Cr)	0,35-0,75	10-14	58-62	≈28	
(66Ni17Cr)	0,35-0,75	15-19	64-68	≈17	
NiCr Wrought (80Ni20Cr)	0,10	20	80	≈4	Ti0,5
(52Ni22Cr Co Mo Al)	0,07	22	52	≈3	Co12,5 Mo9 Al1,2
(78Ni16Cr)	0,05	16	78	≈3	Al4,5
(58Ni22CrWMo)	0,10	22	58	≈3	W14 Mo2

The strength properties at high temperatures can be determined and reported in two ways:

1. Short-Time Strength Properties
2. Long-Time Strength Properties.
    - Sufficient to ensure that the test temperature has been uniformly attained throughout the test piece.
    - As an indication of the reduction in strength properties which occurs, typical tensile and yield strengths for wrought FeCrNi stainless steels at high temperatures as per Table 2.
    - However, such results have little relevance for predicting the performance of materials exposed for long times (often years) at high temperatures. Therefore, long-time strength properties need to be determined.

While much of the literature surrounding elevated temperature properties of stainless steels is focused on long term exposure, the short-term properties are gaining increased attention due to their possible use as structural products for high rise buildings due to their resistance to fire, where stainless steels can sustain much higher safe loads than conventional structural steels at temperatures experienced in a building fire.

LONG-TIME STRENGTH PROPERTIES

CREEP AND RUPTURE PROPERTIES

If stainless steels and stainless alloys are subjected to loads at high temperatures, they will undergo a continuous slow deformation (ie plastic strain) and eventually rupture (ie break) at stresses below the yield strength as determined in short-time testing.

Long-time strength properties are dependent on stress, temperature and time. For example for structures or components operating at high temperatures either the stress has to be limited to levels that will result in an allowable amount of deformation (strain) and/or eventual rupture over a predictable and acceptable time period for a specific operating temperature - or if the stress cannot be sufficiently lowered then it must be accepted that a greater amount of strain will take place and/or rupture will occur within a shorter time period or the temperature will have to be lowered to obtain the required service life without exceeding the allowable strain and/or causing rupture. The continuous slow plastic strain (deformation) which takes place is realistically termed CREEP. See Figure 1.

The amount or extent of plastic strain that takes place with time is termed the CREEP RATE, which is dependent on both stress and temperature reported as either %/hr; or 1% in 1 000, 10 000 or 100 000 hrs reported in either tabular or graphical format. See Figure 2.

The stress required to produce rupture is termed the RUPTURE STRESS which is usually reported as the STRESS RUPTURE, i.e. the stress at different temperatures that will result in rupture at a specified time (100, 10 00, 10 000 or 100 000 hrs).

For example:

40MPa at 750°C for rupture in 10 000 hrs.
28MPa at 750°C for rupture in 100 000 hrs.
23MPa at 800°C for rupture in 10 000 hrs.
18MPa at 800°C for rupture in 100 000 hrs.

But also reported as the RUPTURE TIME, i.e. the time at which rupture will occur at different temperatures for a specific stress.

For example:

3 000 hrs at 800°C for a stress of 30MPa
20 000 hrs at 750°C for a stress of 30MPa.

Both STRESS-RUPTURE and RUPTURE TIME are reported in either tabular or graphical format as shown in Figure 3.

STRESS-RUPTURE properties at various temperatures.

Creep and rupture properties are often

TABLE 2: Typical ambient temperature and short time high temperature strength properties for FeCrNi stainless steels to indicate the reduction that occurs

MATERIAL	AMBIENT TEMP Tensile/Yield (MPa)	600°C Tensile/Yield (MPa)	850°C Tensile/Yield (MPa)
18Cr8Ni FeCrNi	585 / 240	360/115	120/50
25Cr20Ni FeCrNi	620 / 290	465/150	180/80

FIGURE 1: A creep curve obtained by testing a specimen of the material at a constant high temperature

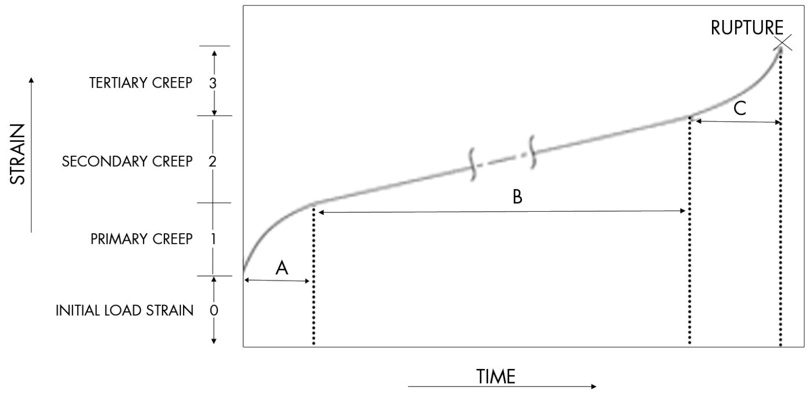


FIGURE 2: Creep rates at various temperatures

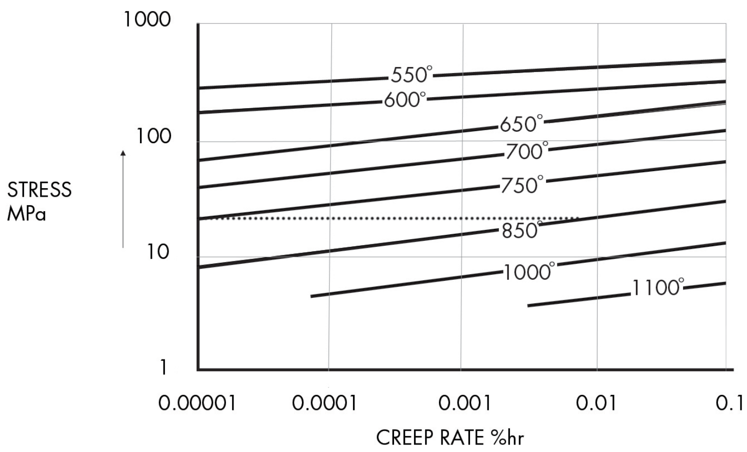
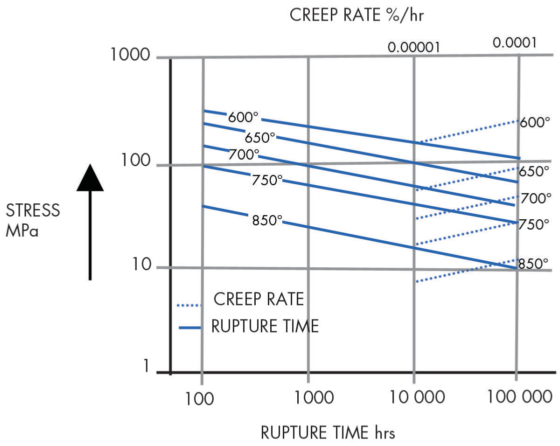


FIGURE 3: Stress vs rupture time and creep rate at various temperatures



reported in a combined graphical format as shown in Figure 4 on the previous page. Such representation is especially useful in illustrating the inter-relationship between creep and rupture properties.

A stress-temperature combination that results in an allowable creep rate may prove to be unacceptable in so far as it causes rupture in a time shorter than the desired service life; and vice versa.

The effect of the Log-Log scales on the axes of Figures 2 and 3 should be noted, especially in that relatively small differences in stress and temperature (either individually or in combination) can bring about large changes in creep rate and rupture time values.

FACTORS AFFECTING CREEP AND RUPTURE PROPERTIES

Creep and rupture properties are dependent on and affected by:

1. Chemical composition
2. Microstructure
    - Crystal structure
    - Grain size
3. Product form
4. Operating conditions
    - Stress variations
    - Temperature cycling
    - Corrosion

1. CHEMICAL COMPOSITION and CRYSTAL STRUCTURE

The chemical composition has a major influence on the crystal structure that is formed. Wrought materials exhibit a far more uniform crystal structure than do castings due to the mechanical refinement which occurs during hot (and cold) working processes.

The following factors are significant:

- Both chemical composition and wrought or cast microstructure affect both creep and rupture properties to different extents.
- Carbon (C) has a great influence and is a major contributing factor to the significantly superior properties of the cast heat resisting materials.
- Nitrogen (N) additions to FeCrNi stainless steels improve the high temperature strengths, resulting in creep and rupture properties which can be 50-100% higher than the N-free steels.
- Heat treatment can also influence the microstructure.
- Some compositional balances may lead to crystal structure (phase) instability at certain temperatures. Longer exposure times increase the tendency for crystal structure changes to occur.

2. GRAIN SIZE

- Coarser grain sizes tend to lower the creep rate and increase the rupture strength.
- The effect is more marked at higher temperatures and for longer exposure times.
- The inherent coarser grain size of castings is an additional contributing factor to their superior creep and rupture properties.
- Grain size is more easily modified in wrought materials by employing different heat treatment parameters. In cast materials, the grain size which results from the simple solidification from the molten state is only slightly affected by heat treatment.
- In castings required for critical applications directional solidification and controlled cooling rates may be employed to produce both the grain size and shape required.
- Fine grain size improves the ductility. Applications that require an increased ductility (e.g. to better accommodate thermal stresses induced by rapid temperature cycling) are better served by finer grain sizes.

CREEP AND RUPTURE ARE AFFECTED BY COMPOSITION, MICROSTRUCTURE, PRODUCT FORM AND VARIOUS OPERATING CONDITIONS

3. PRODUCT FORM AND SHAPE

- Among the wrought products there can be slight differences between the properties of plate, sheet, bar, forgings, pipe/tube, bolts etc due to the micro-structure modifications which occur during the processing operations.
- Welding decreases creep and rupture properties, the effect being greater at higher temperatures and for longer exposure times.
- The use of correct welding consumables is very important in minimising this effect.
- In the welding of stainless steel use consumables that result in a minimum ferrite content of the weld metal. In the welding of stainless alloys use consumables specifically developed for the actual proprietary grade being fabricated.
- Non-uniformity of section generally lowers the creep and rupture properties due to the change in the stress configuration that occurs at the change of section. A gradual change of section will assist in minimising this effect.

4. OPERATING CONDITIONS

In service the conditions of stress, temperature and corrosion can vary and be substantially different from those that prevailed in the laboratory testing used to determine published creep/rupture properties.

The resultant change in properties is not easy to quantify but will be relative to the extent and severity of the variations in these factors, either alone or in combination.

- The stress imposed by known mechanical loads can either be static or fluctuating.
- Thermal fatigue is caused by crystal structure instability/change or fluctuating thermal stress brought about by frequent temperature cycling or large ranges of temperature cycling or thermal shock, ie the rapid increase or decrease of temperature in short times (e.g. quenching).
- The stress configuration will be altered by corrosion which causes either changes to the surface profile which may result in stress raisers and/or loss of metal thickness which results in an increase in stress.

HIGH TEMPERATURE EMBRITTLEMENT

High temperature embrittlement is the loss of ductility and toughness caused by crystal structure (phase) changes that occur during prolonged exposures to high temperatures. The two most important embrittling mechanisms are:

1. SIGMA (ð)

This phase may form at high temperatures in both the ferritic (FeCr) and austenitic (FeCrNi) stainless steel grades.

- In addition to its influence on creep rupture properties, it has a serious secondary embrittling effect. High temperature equipment can suffer catastrophic failure if subjected to shock loads or deformation during repair and maintenance at ambient temperatures.

- It is essentially a complex FeCr intermetallic phase.
- It forms over the range of 550°-875°C.
- It forms more readily from the ferritic crystal structure in stainless steels containing > 20%Cr. As the Cr content decreases Sigma is less easily formed.
- If the embrittling effect of Sigma is an important consideration, the ferrite content of weld deposits and cast structures must be avoided by using compositional balances which develop a fully stabilized austenitic crystal structure.
- The ferrite content of duplex stainless steels and hence their susceptibility to Sigma formation, essentially preclude this classification of stainless steels from applications at the higher elevated temperatures and at high temperatures.

The increased Ni content of the FeNiCr and NiCrFe stainless alloys fully stabilizes the austenitic crystal structure into regions well removed from the Sigma formation.

2. 475° EMBRITTLEMENT

This elevated temperature embrittling effect is confined to the ferritic crystal structure.

At these elevated temperatures, there is a loss of toughness, but tensile/yield strengths and ductility are little affected.

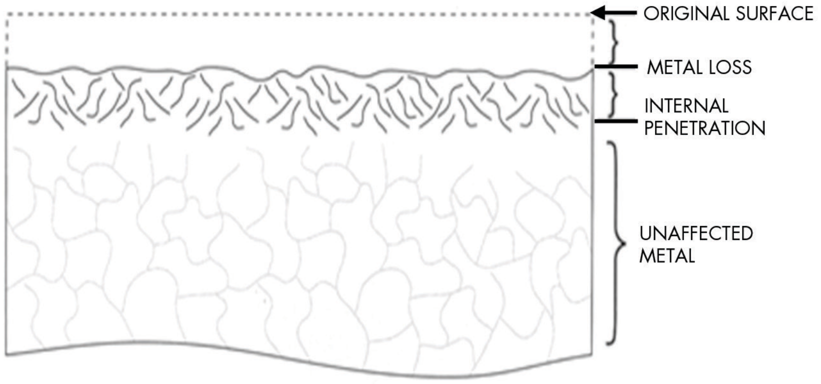
CORROSION RESISTANCE

Corrosion at high temperatures differs from aqueous corrosion in that it is not electro-chemical.

Gaseous corrosion is the most commonly encountered form of high temperature corrosion in which a chemical reaction occurs between the aggressive species in the atmosphere and the constituent alloying elements of the stainless steel/Alloy to form chemical compounds, either as a scale on the metal surface or as precipitates within the metal matrix. The mechanisms of gaseous corrosion include:

- Oxidation
- Sulphidation
- Carburization
- Nitridation
- Hydrogenation

FIGURE 6: The corrosive effect of both metal loss and internal penetration



- Halogenation

The other form of high temperature corrosion which is less commonly encountered is dry corrosion by solid substances causing alloying and fluxing reactions to take place.

The mechanisms of dry corrosion include:

- Molten Salt Corrosion
- Ash/Salt Corrosion
- Molten Metal Corrosion

The reactions that take place in all high temperature corrosion mechanisms are complex and are affected by:

- The chemical composition of the stainless steel/alloy.
- The complex and usually very different environments which are encountered in industrial processes.

In the sections that follow the basic reactions which prevail in each of the high temperature corrosion mechanisms will be covered. However, it is stressed that in practical situations more than one mechanism is normally operative and that which predominates will essentially depend on the predominant aggressive species present in the environment.

The interactive nature of the corrosion mechanisms is usually synergistic resulting in a rate of attack greater than that of each individual mechanism.

Two forms of corrosive damage occur:

1. Surface attack resulting in loss/wastage/thinning of the metal.
2. Internal penetration into the metal.

In some instances, both may occur concurrently.

The rate of high temperature corrosion is seldom constant as it is governed by several inter-related and interactive factors which include:

- The actual conditions which prevail within the environment. Any fluctuations or changes can significantly alter the corrosion rate.
- The nature of the scale formed on the surface, and hence the amount of protection afforded by such scale.
- E.g. is it continuous, cracked, porous, thick/thin, adherent/loose, of low melting point, of variable composition In many cases a protective (usually an oxide) scale forms which will for some time resist or slow down the rate of attack. However, such a scale may (and normally does) at some stage break down, after which a rapid increase in the corrosion rate results. This is termed breakaway corrosion, and the elapsed time period before this will occur is difficult to predict.
  - The diffusibility of certain elements through the scale and/or into the metal to form chemical compounds (precipitates) within the matrix will vary over time.
  - The degree of alteration of the metal composition at the metal/scale interface.
  - Dissolution of the stainless steel/alloy, or some of its alloying elements, into the molten metal being contained.
  - Alloying within the matrix of the stainless steel/alloy due to the solubility of the molten metal being contained in the stainless steel/alloy.
  - Fluxing of the scale causing it to break down or melt.

The corrosion rates are measured and reported on different bases.

- Change of mass, either as a gain or a loss, i.e. +or- mg/cm2 or +or- %. The problems associated with this basis of measurement include:
  - Loss of scale (corrosion

product) can occur by flaking or spalling which results in incorrect mass measurements.

- Different basic compositions give rise to scales of different densities (i.e. not exactly comparable) = the extent of internal attack and resultant damage is not measured.
- Total depth of attack, which is the combined assessment of both metal loss and depth of internal penetration. See Figure 6 .
- Results reported in this way are more meaningful for performance comparison purposes.

OXIDATION

Oxidation is the most common mechanism of high temperature corrosion.

In most industrial high temperature environments, even if other corrosion mechanisms predominate, oxidation will usually occur to a degree. The oxidation that occurs is often the protective mechanism which inhibits the other forms of corrosive attack.

In its purest and simplest form oxidation occurs in air.

Plain C steels will begin to suffer high temperature oxidation once the temperature exceeds 550°C, the rate of oxidation increasing with temperature until at approximately 750°C it has become very rapid

This is due to the non-protective nature of the iron (Fe) oxide scale which is formed.

Chromium (Cr) has a high affinity for oxygen. The Cr contents of stainless steel and alloys therefore result in an excellent resistance to high temperature oxidation.

Stainless steels/alloys are thus standard materials used for resistance to oxidation at temperatures in excess of 650°C.

More than about 13% Cr leads to the formation of an oxide scale rich in Cr. At ± 18% Cr the continuous nature of the chromium Oxide(Cr2O3) scale formed renders it highly protective. Increased Cr contents of up to 25-28% Cr further increases the resistance to oxidation enabling higher temperatures to be handled.

However, whereas the wrought and cast FeCr stainless steels containing 25% and 28% Cr have excellent oxidation resistance, their mechanical properties at temperatures in excess of 650°C are inferior. Therefore, the FeCrNi

stainless steels, the FeNiCr and NiCrFe stainless alloys (all of which contain between ± 18-26% Cr) are preferred because of their superior mechanical properties at high temperatures. The maximum service temperatures under continuous/isothermal operating temperatures are typically 925°C for 18Cr8Ni FeCrNi stainless steels and 1100°-1150°C for 25Cr20Ni FeCrNi stainless steels, FeNiCr and NiCrFe stainless alloys.

However, if the operating conditions involve intermittent use or thermal cycling at high temperatures the maximum service temperatures are lowered by approximately 60°-110°C

The difference in expansion/contraction characteristics of the scale and metal, and hence the spalling resistance under cyclic temperature conditions varies with the chemical composition -25Cr FeCr stainless steel exhibits moderate resistance as the expansion/contraction of the metal and scale is similar.

The formation of an AI2O3 scale is significantly more protective than Cr2O3 scale at these high temperatures.

Whereas the purest form of high temperature oxidation occurs in air, any gaseous mixture which contains oxygen will cause oxidation. Environments which result from combustion are typical of such gaseous mixtures, and are regarded as oxidizing if excess (free) oxygen is present, ie there is more oxygen than is theoretically required for the combustion reaction. The atmosphere will contain O_2, H_2O, CO_2 and small amounts of CO.

OXIDISATION IS THE MOST COMMON FORM OF HIGH TEMPERATURE CORROSION - AS THIS IS THE NATURE OF STAINLESS STEEL

Water vapour (H_2O) increases the rate of oxidation, and service temperatures for 18Cr8Ni and 25Cr20Ni FeCrNi stainless steels should be reduced by 150ºC and 100ºC respectively from the allowable service temperatures in air.

SULPHIDATION

Many industrial atmospheres contain sulphur (S) in some form and therefore sulphidation is a common form of high temperature corrosion.

- Fuels used for combustion, both coals and oils, commonly contain S.
- S contamination of the atmosphere also results from processes, e.g. roasting of sulphide ores, petrochemical refining, waste incineration, gasification of coal.
- S contamination of the surface of the metal may occur during fabrication, and good housekeeping practices to avoid this are of prime importance.

An atmosphere containing S can be oxidizing but is more usually reducing in nature, ie no excess (free) oxygen exists as the completeness of the reactions are controlled either with just sufficient oxygen (stoichiometric) or insufficient oxygen (sub-stoichiometric).

The gases may contain S vapour, SO2, SO_3, H_2S, H_2, CO and CO_2 in varying concentrations.

Sulphidation attack is more severe than oxidation.

Sulphur vapour environments cause severe sulphidation because no oxygen is available to form a protective oxide scale.

CARBURIZATION

Carburization is caused by the diffusion of C into the metal to form carbides both within the crystal structure and at the grain boundaries Embrittlement and a decrease of other mechanical properties results.

Carburization is caused by solid carbonaceous material and gaseous atmospheres containing hydrocarbon gases e.g. methane (CH_4) and ethylene (C_2H_6). Such conditions are encountered in heat treatment processes, the petro chemical industry and in the production of carbon fibres.

The carburization profile is such that it is higher at and near the surface, and decreases with increased depth of penetration.

The profile can change depending on alloy composition to vary between either a high concentration gradient to shallow depth, or a slight concentration gradient to greater depths of penetration

Carburization can penetrate up to 10mm below the surface of the metal.

Both the composition of the metal and the gaseous atmosphere affect the rate and extent of carburization.

The temperatures required for carburization to occur are more than ± 850°C.

- As the temperature increases to higher levels the rate of carburization increases to a significant degree.

- Compositions and conditions which afford resistance to carburization will raise the temperature before that at which an onset of carburization occurs.

METAL DUSTING

This is another form of carburization attack which takes place at lower temperatures of 450°-900°C and causes pitting or metal wastage and thinning. The corrosion products on the surface typically have the appearance of a dust consisting of powders of metals as oxides or carbides as well as carbon soot. The mechanism is thought to be caused by alternating carburizing and oxidising conditions.

NITRIDATION

Molecular nitrogen (N_2) may in most instances be considered as an inert gas for steels and alloys at high temperatures, e.g. the nitrogen fraction of air or combustion gases at high temperatures does not result in nitridation, and in many instances N_2 is used as a protective atmosphere.

Only in the rare conditions in which pure 100% N_2 comes into contact with a metal surface devoid of any oxide scale/film may molecular N_2 cause nitridation.

However atomic nitrogen (N) will penetrate most steels and alloys to form hard and brittle nitrides of Fe, Cr, Ti, Al, Mo as precipitates within the matrix and at the grain boundaries. An impairment of the mechanical properties results.

Atomic nitrogen (N) is typically encountered in process plant used for ammonia production; dissociation and cracking of ammonia; production of nitric acid, nylon, melamine and in nitriding heat treatment processes.

The severity of nitridation depends on concentration, pressure, temperature of the ammonia atmosphere and the composition of the steel/alloy

At lower temperatures of ± 500°- 550°C the diffusion of N is low and nitridation is confined to the surface layers only. However, at higher temperatures of 950°-1000°C the diffusion rate is rapid and internal nitridation to significant penetration depths will occur.

HALOGENATION

Environments of, or containing, Halogens e.g. Chlorine (Cl_2), Hydrogen Chloride (HCI), Fluorine (F_2) and Hydrogen Fluoride (HF) are extremely aggressive.

This is due to chloride and fluoride scales having low melting points and being easily volatilized.

Therefore, little protection is afforded to the metal surface the lowest corrosion rates, which are best described are giving useful resistance, are often >10 times the corrosion rates considered for general high temperature corrosion resistance.

Environments which contain halogens are typically encountered in mineral processing, the production of some grades of plastics and in waste incineration.

In most cases, high levels of Ni result in the best resistance as the nickel halides formed have higher melting points and result in more adherent scales.

In pure halogen gases, useful corrosion resistance is usually limited to the elevated range of temperatures only; < ± 300°C for stainless steels and < ± 500°C for stainless alloys.

MOLTEN SALT CORROSION

Metal components that contain molten salts suffer corrosion due to the salts exerting a fluxing effect, i.e. either reacting with the metal, or any oxide scale which may form on the surface, to form low melting point compounds which are thus easily removed from the surface.

General thinning/wastage usually results, but pitting and intergranular attack can also occur.

Molten salt environments are encountered in the heat treatment processes, mineral processing and as a heat transfer medium in solar collectors.

MOLTEN ASH/ SALT CORROSION

Molten ash/salt corrosion occurs under conditions of combustion.

- It involves not only the gaseous species but also aggressive constituents arising from the fuel or other products being combusted.
- The aggressive gaseous species can contain sulphur (e.g. from coals/oils), chlorides (e.g. combustion air under marine environments, or as contaminants from the material being combusted).
- The aggressive dry constituents can include sulphates (e.g. from coals/oils), oxides (e.g. vanadium pentoxide, sodium oxides from oils), metals (e.g. zinc, lead, potassium from incineration of waste).

The corrosion mechanism that occurs is therefore extremely complex as it can involve co-existent oxidation, sulphidation, reaction of salts with the scales formed exerting a fluxing action, and actual salt deposition on the surface.

Oxidation usually takes place initially and affords some protection until broken down by the other aggressive species.

MOLTEN METAL CORROSION

High temperature corrosion of metal can occur either by the dissolution of the containment metal or its alloy constituents into the liquid metal being contained, i.e. dissolution type of attack or by the molten metal being contained alloying with the containment metal (or its alloy constituents) to cause a penetrative type of attack.

In general terms, stainless steels and stainless alloys are poor candidate materials to resist corrosion by most molten metals.

However, lead (Pb) and some copper (Cu) alloys can be handled by the FeCr stainless steels.

CONCLUSION

The factors involved in the performance of stainless steels and stainless alloys with respect to both their mechanical properties and corrosion resistance at high temperatures have been briefly covered.

Due to the complexity of the interactive conditions which usually prevail and their corresponding effects, the choice of the most suitable material is not an easy matter.

Often a material which is the most corrosion resistant will not have the required mechanical properties and vice versa.

Further in some instances the performance ranking will not show a correlation with respect to a trend of alloy content of the steel or alloy.

A vast number of both standard and proprietary grades of stainless steel and stainless alloy heat resistance materials are available. In some cases the final selection may depend on trials of several candidate materials. The manufacturers of these materials have a wealth of experience and performance data obtained from historical applications, and have been found. Sassda is always both able and willing to assist.

It is trusted that with the basic appreciation of the factors involved the conditions critical to the performance in the required application will be determined and defined, which will assist in subsequent communication between user and supplier leading to the selection and application of the best possible material.

For a more comprehensive guide to the terms outlined in the guide, please contact sassda at info@sassda.co.za or call 011 883 0119.