ALLOY 24 (1.4565) - Material Datasheet

Additional Information

- *Extended Material Data & Corrosion Performance (*)*
- *Fabrication Guidelines (*)*
- *Welding Guidelines (*)*
- *References / Literature (*)*
- *Availability – Product Forms & Dimensions (*)*

(*) Documents on Demand – see our website

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" We serve our Customer demands in search for reliable information on Alloy 24. Appreciating this, we decided to publish an extended Material Datasheet, a compilation of Facts, Figures and Guidelines, focused on our re-invented Super-Austenite - Alloy 24"

Alloy Description - Specifications & Applications

Alloy 24 (1.4565) is a fully austenitic stainless steel which features both, high strength and excellent corrosion resistance in a wide range of corrosive media.

Alloy 24 is recommended for use especially in equipment for chemical industries. Its resistance to chloride induced pitting and crevice corrosion enables it to be used successfully in the production and transport of oil and gas on on-shore and off-shores facilities. Because of outstanding corrosion resistance, it is very suitable for applications in land-based and in on-board flue gas desulphurization (FGD) systems and other environmental technologies. The performance of Alloy 24 in seawater environments of all kinds, is superior.

Alloy 24 (4565) material is covered by the following specifications

- ASTM A167, A182, A240, A249, A358, A403, A479, A480
- EN 10088 2/3/4 (1.4565 - X1 Gr Ni Mo Mn Nb N-24.17.5)
- AFNOR Z2 CNMO 23.17.5 AZ
- NACE Standard MR-01-75 up to 29 Rc Hardness
- ASME Code Case 2146

Alloy 24 - Applications Overview

Alloy 24 was originally developed for applications in chloride containing environments and especially for seawater applications. The high nitrogen content ensures the stable austenitic structure, the high strength and the outstanding pitting and crevice corrosion resistance, even in the as-welded condition.

Offshore Platforms

Flow lines, sea water cooling, deluge systems, fire fighting pressurized lines using sea water and sub-sea tie ins/conversions.

Chemical and Petrochemical Industry

High chloride, high temperature, low pH conditions which cause SCC or pitting and crevice corrosion of lower grades. Depending on the environment, Alloy 24 can withstand temperatures in excess of 300˚C which rule out the use of super-duplex alloys.

Pulp and Paper Industry

C/D stage bleaching vats, drums and all associated piping. including aggressive vapor phase conditions

Climate & Environmental Pollution Control

Landbased and shipbased “On-Board” Flue Gas Desulphurization systems (FGD) incorporating wet gas scrubbers, electro-static precipitators and associated pipings and ductwork.

Power Transformation & Salt Crystallization (Evaporators)

Brine concentrators and evaporators; geothermal downhole tubings (deep wells).

Seawater & Heat Transfer Processes

Seawater desalination plants with shell and tube-heat exchangers as well as plate heat exchangers where hot chloride solutions are associated with tight crevices.

Boating

High strength, corrosion resistant yacht rigging

Chemical composition

The development of ALLOY 24 - (1.4565) goes back to Amanox Alloys. These steels are well suitable for marine applications being nonmagnetic and providing a yield strength of more than 430 MPa. For an additional enhancement of the corrosion performance, the AMANOX Alloys composition was redesigned by:

- increasing the Mo content to 4,5 %
- lowering silicon and carbon significantly and
- restrict the niobium content

As a result, Alloy 24 combines high mechanical strength with excellent corrosion resistance in a wide range of corrosive media, especially in chloride containing solutions. Alloy 24 is now produced in the typical composition as shown in Table 1

Table 1 - Chemical Composition, nominal (weight-%)

C	Si	Mn	Cr	Mo	Ni	N	Nb
≤0.03	≤1.0	3.5-6.5	23.0-25.0	3.5-5,0	16.0-18.0	0,4-0,6	≤0,1

Physical Properties

Table 2.1 - Physical Properties (1)

Density kg/dm^3 lb/cu in	Thermal conductivity at 20 °C/ 70°F W/m • K	Specific heat capacity at 20 °C / 70°F J/kg • K	Electrical resistance at 20 °C /70°F Ohm • mm^2/m	Magnetizability
8,0 0.29	12.0	450	0.92	none*

(*) Slight potential for magnetizability after solution annealing and quenching

Table 2.2 - Physical Properties (2)

Modulus of elasticity 10^3 N/mm^2 / kp/sq. in				Coefficient of thermal expansion between 20 °C					
20°C 70 °F	200 °C 390 °F	400 °C 750 °F	500 °C 930 °F		100°C 210 °F	200 °C 390 °F	300 °C 570 °F	400 °C 750 °F	500 °C 930 °F
190	176	164	159	10^{-6}/K	14,5	15.5	16.3	16.8	17.2
28	26	24	23	10^{-6}/F	8.0	8.6	9.0	9.3	9.5

Microstructural properties

Nitrogen is an important alloying element in austenitic stainless steels due to its high solubility in the face centered cubic structure, austenite. The addition of Manganese increases the solubility of nitrogen even further. Researchers discovered that nitrogen additions to higher alloyed austenitic steels retarded both carbide and intermetallic phase precipitation. In combination with the knowledge that dissolved nitrogen improves mechanical strength and pitting corrosion resistance this pointed at new opportunities to develop high performance stainless alloys with less amounts of the expensive nickel.

Alloy 24 keeps a stable austenitic structure within a wide temperature range. As with all super austenitic steels, the structure is fully stable against martensite formation upon cold deformation.

Therefore, the steel can be produced in thick sections without precipitates in solution annealed and quenched condition.

The iso-toughness data of Alloy 24 shows the ageing response due to which the absorbed energy in the Charpy impact test has decreased to the 100 J level. Alloy 24 (1.4565) retains an impact resistance in excess of 100 J after ageing at 950° C for nearly one hour.

This enables safe welding operations without the risk of embrittlement in the heat affected zone (HAZ) of the parent material.

Mechanical Properties

Due to the high nitrogen content Alloy 24 has a very high 0,2 % yield strength and tensile strength comparable to that of the common duplex grades, e.g. 2205 (UNS S 31803) but with a remarkable higher ductility.

At ambient temperature the 0,2 % yield strength of Alloy 24 is beyond 420 Mpa. At elevated temperature (300°C) it still meets the room temperature values of other austenitic grades like 904L or 3I7LN.

Table 3.1 - Mechanical Properties at Room Temperature (20°C)

Heat treated condition	0.2 % Yield strength min. N/mm^2 kp/sq. in	1 % Yield strength min. N/mm^2 kp/sq. in	Tensile strength N/mm^2 kp/sq. in	Elongation ($L_0 = 5\ d_0$) or2" % min. lang.	transv.	Notch impact toughness (ISOV-specimen) min. 3 / transv.
Solution annealed and quenched	420	460	800-950	30	30	70
	61	67	115 - 138	30	30	55

Table 3.2 - Mechanical Properties at elevated Temperatures [EN 10088-2 SI conv. to US Units/ ≈ASTM A 240]

Temperatures °C / °F	0.2 % Yield strength min. N/mm² kp/sq. in	1 % Yield strength min. N/mm² kp/sq. in
100/212	**350/51**	**400/58**
150/210	**310/45**	**355/52**
200/392	**270/39**	**310/45**
250/482	**255/37**	**290/42**
300/572	**240/35**	**270/40**
350/662	**225/33**	**255/37**
400/752	**210/30**	**240/35**
450/842	**210/30**	**240/35**
500/932	**210/30**	**240/35**

Table 3.3 - Mechanical Properties at elevated Temperatures, nominal for plates
[Source: Qualified Steel Producers Datasheet as of 01-2020;
SI conv. to US Units]

Temperatures °C / °F	0.2 % Yield strength min. N/mm² kp/sq. in	1 % Yield strength min. N/mm² kp/sq. in	Tensile strength min. N/mm² kp/sq. in
100/212	330/48	355/51	**760/110**
200/392	290/42	315/46	**690/100**
300/572	290/42	315/46	**660/96**
400/752	290/42	305/44	**650/94**
500/932	260/38	290/42	**610/88**

Elongation (A): 58%
Impact toughness: > 100 J/cm² (70 ft.lbs) at -196°C (-320F)
Hardness values: HV_{10} [180 - 220]

Corrosion Resistance

The primary intention in developing Alloy 24 was to provide a material with excellent resistance to chloride-induced pitting and crevice corrosion. These conditions prevail in all offshore- and onshore-based seawater applications and in the shipbuilding industry. Landbased seawater desalination plants as well as brackish water conditions are long-established application fields for Alloy 24.

The chromium and molybdenum contents and the high nitrogen content result in a pitting index of significantly higher than 50. The Pitting Resistance Equivalent Number (PREN) is calculated according to:

PREN = % Cr + 3.3 % Mo + 30 % N

and is considered a measure for the excellent resistance to pitting and crevice corrosion. Taking into account the minor variations of the chemical composition, Alloy 24 indicates a PREN of 52.

Due to the stable austenitic structure, which is precipitation free in the solution annealed and quenched condition, Alloy 24 also features an excellent overall corrosion resistance in a welded state to a wide range of aggressive media including oxidizing and reducing acids even when these are contaminated with halogenide impurities.

Intergranular Corrosion

Alloy 24 due to it’s strictly limited Carbon-content as well as with the increased Nitrogen content is immune to IGC in the properly applied solution-annealed and rapidly quenched condition. For safety purposes, especially in the production of thicker section plates and bars, the IGC-Test acc. to EN ISO-3651-2 may be specified.

Local Corrosion Performance (Pitting & Crevice Corrosion)

Testing Alloy 24 in ferric chloride solution according to standard ASTM G 48 (E), a maximum Critical Pitting Temperature (CPT) of 85 °C was determined. Under these testing conditions the same CPT was achieved only by the Ni-base Alloy 625 N06625 , see Fig. 1 (1).

A comparable behavior was found testing Alloy 24 in ferric chloride solution under crevice conditions according to MTI standard or, later on ASTM G 48 (F). The actual critical crevice temperature range of 45 - 55 °C is achieved only by the Ni-base alloy 625, under the same conditions (2).

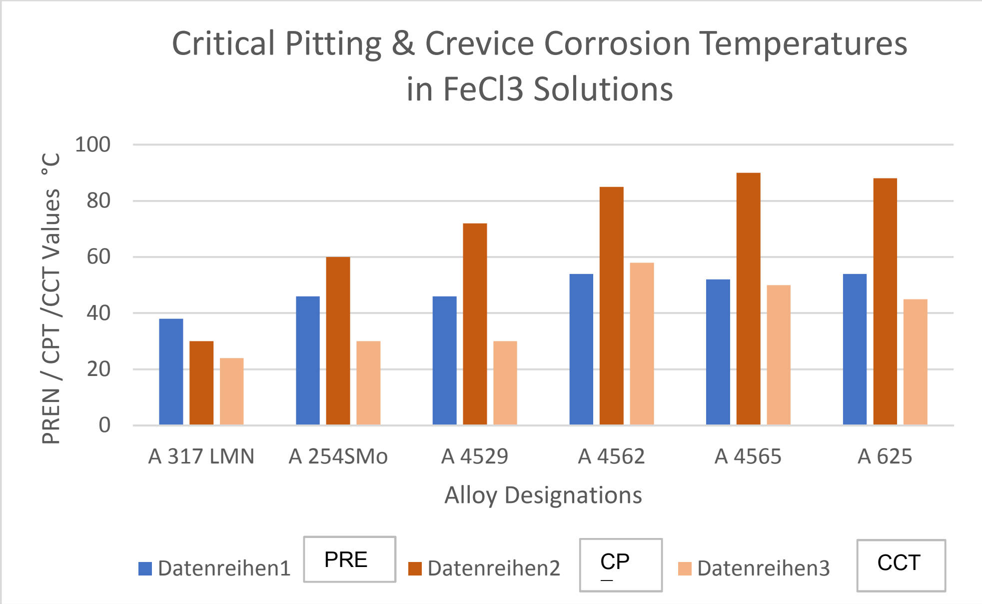

Figure 1 - Critical Pitting & Crevice Corrosion Temperatures in FeCl3 Solutions;
Tests acc to ASTM G48 E & F

Remarks

(1) PREN = %Cr + 3.3 x %Mo + 30 x %N2 > Factor for N2 focused on Pitting Corrosion

(2) CCT values in any case are recorded about 20 – 30 degrees °C lower compared to CPT values; this is due to the immanent higher aggressivity of local corrosion in oxygen-depleted areas, e.g. under crevices.

Fig. 2 compares the CPT's determined in ferric chloride solution according to the ASTM G 48-76 standard, of a GTA-welded {no filler) test specimen (70 °C) and of a specimen welded with the recommended filler material Thermanit NiMo C (75 °C) which are only 15 and 10 °C respectively lower than that of the unwelded specimen (85 °C).This assures good corrosion resistance of the welded structures without post-weld heat treatment.

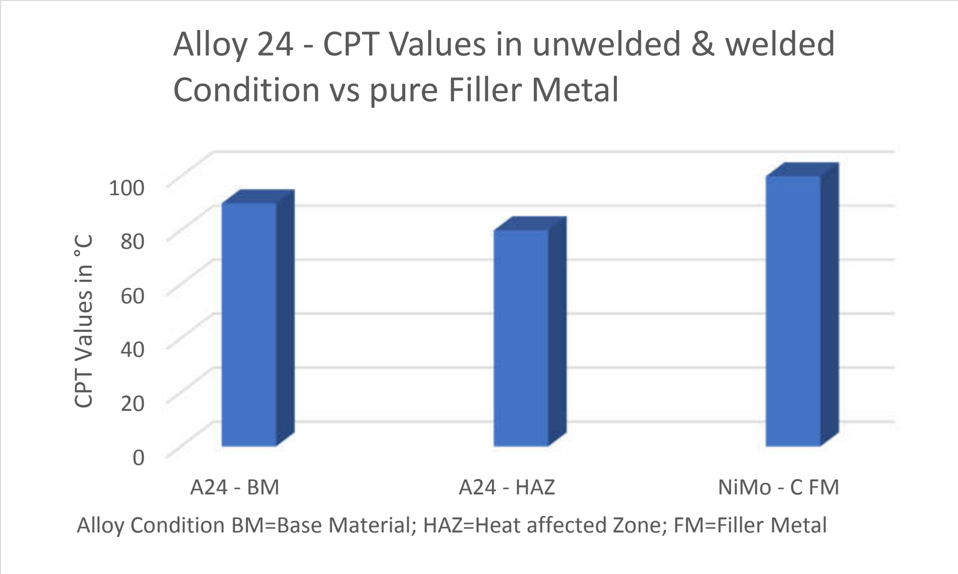

Figure 2 - Critical Pitting Temperature of Alloy 24 in welded & unwelded Condition; $FeCl_3$ Test acc to ASTM G48 (E);
HAZ shows only slight drop in CPT vs BM A24; Filler Metal NiMo C is included for Reference only

Pitting Corrosion in 1m Sodiumchloride NaCl (ASTM G150)

The critical pitting temperatures were determined potentiostatically at 950 mV in a less aggressive 3 % NaCl solution. The diagram in Figure 3 shows the borderline of 90°C for the critical pitting temperature (CPT). This has to be compared with the 95°C in the solution annealed condition. After ageing for a period of 12 min. at 900°C the CPT is still 90°C. This demonstrates again that welding operations can be done without sensitization of Alloy 24 (1.*4565*).

Another remarkable result is that there is no longer a clear distinction between Nitrogen-bearing Alloy 24 and higher-graded Alloy 625.

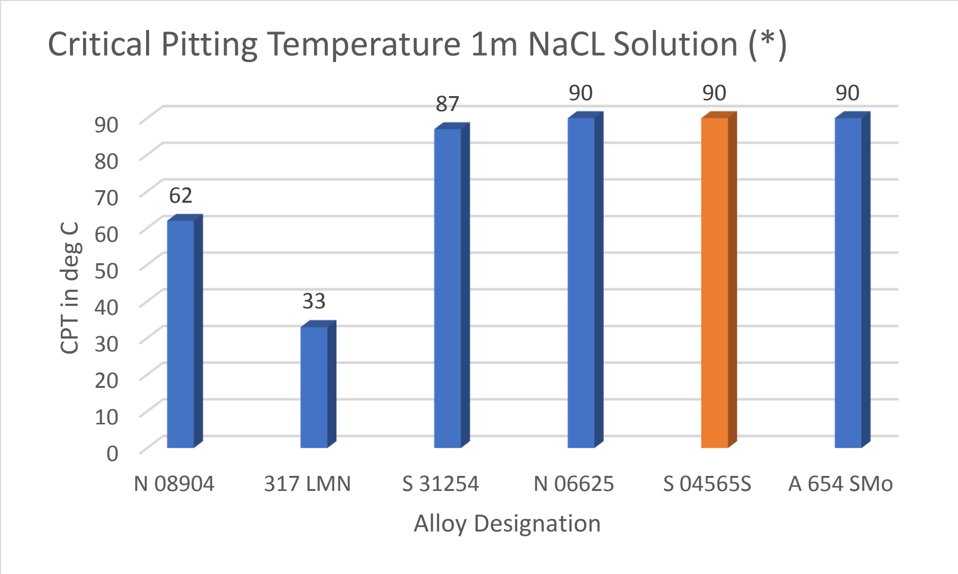

Figure 3 - Critical Pitting Temperature of high alloyed Stainless Steels in 1m NaCl Solution acc to ASTM G 150 / AVESTA Cell (CPT variation ± 3°C)

Corrosion Performance in Seawater

Alloy 24 (1.4565) was developed based on a family of marine alloys. Therefore, seawater-based applications were in the primary focus of the research teams.

Exposure tests to mimic these conditions were performed under rough North Sea conditions with a large number of multi-sample creviced test racks. The total test duration under varying climate conditions added up to 5 years!

In a group of seven alloys, Alloy 24 (1.4565) was among the three best performing candidates showing no sign of uniform or crevice corrosion, neither on the bare surfaces nor under the tight crevices. Even the settlement and growth of barnacles and shells could not impair the excellent corrosion performance of Alloy 24. Standard Stainless Steels e.g. grades 316, 926 and even Alloy 28 showed heavy attack after 3 years intermediate inspection.

Alloy 24 (1.4565) can be laser welded to produce thin walled (0.35 - 0.40mm) tubing. Corrosion tests have been carried out on tube - tube plate assemblies in simulated MSF desalination plant environments of deaerated sea water at 90° C with oxygen levels of 65, 150 and 750 ppb. Some comparative tests with UNS S31603, S31803 and S32760 were also carried out. Results showed excellent resistance of S34565 to stress corrosion cracking, crevice and pitting corrosion, highlighting its potential as a material for evaporator tubing in MSF plants.

Erosion corrosion is another challenge in seawater. Test have confirmed that Alloy 24 easily withstands conditions of up to 10 m/sec flowing natural seawater. In extreme tests, e.g. under a velocity of up to 20 - 40 m/sec Alloy 24 was not affected. Alloy 24 bears the potential to improve its immanent erosion corrosion resistance applying procedures to increase the surface hardness locally.

Corrosion Performance under FGD Conditions

Flue-Gas Desulphurization plants (FGD) may be considered as chemical plants incorporated into a power station. The sole purpose is to separate noxious materials, primarily sulfur dioxide, nitrous gases and dust from the flue gases.

Chemical processes occurring in flue-gas desulphurization plants are determined by a wide range of corrosive media with high chloride contents and extreme low pH-values at operating temperatures between 50 and 130 °C. Laboratory tests in a simulated flue-gas condensation liquor show that Alloy 24 - 1.4565 exhibits superior pitting corrosion resistance compared to steels with 6 % molybdenum and is comparable with some nickel-based alloys in this respect, see Fig. 4.
A clear distinction between Standard Stainless Steels, Nickel Alloys and Super-Austenitics is possible.Based on these results and a variety of additional tests and field experience, Alloy 24 can be regarded as suitable for applications in landbased and in on-board installations of absorber and quencher equipment of FGD scrubbing towers. A long list of successful references for applications of Alloy 24 in FGD Systems is available on request.

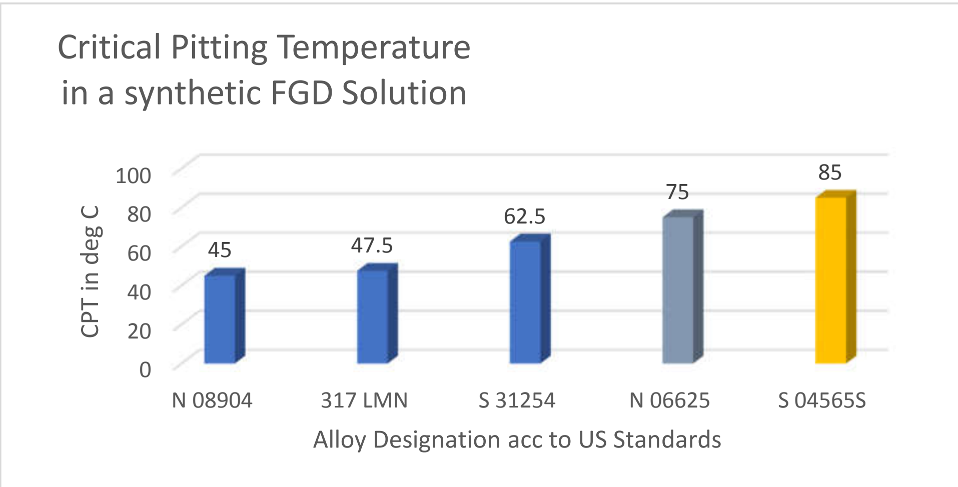

Figure 4 - Critical Pitting Temperature in a synthetic FGD Solution;

Test Solution: 7 vol-% H_2SO_4 / 3 vol-% HCl / 1 mass-% $FeCl_3$ / 1 mass-% $CuCl_2$)

Summary of Benefits applying Alloy 24 (1.4565)

Alloy 24 bears outstanding properties in terms of:

- High strength [+] leading to

  - reduced wall thickness
  - weight savings
  - abrasion/erosion resistance

- Stable austenitic structure [+] a warranty for

  - good workability
  - good toughness, also at low temperatures and as welded
  - no precipitates or thermal aging

- Excellent corrosion resistance [+] the basis for

  - general corrosion in various media
  - pitting and crevice corrosion also in as welded condition
  - stress corrosion cracking resistance in alkali chloride solutions and under sour gas conditions

- Excellent performance and cost-effectiveness [+] yielding in

  - higher strength combined with higher corrosion resistance results in a => reduced wall thickness and => cost savings for the total system

The Multi-Purpose Design of Aloy 24 covers seawater applications as well as equipment for flue gas treatment plants. Along with the excellent weldability Alloy 24 therefore is qualified for modern landbased and for shipbased FGD Units.

Declaration of Liability & Alteration of Contents

Liability Exclusions are applicable to the total content of the Datasheet, e.g. Material Data, Figures, Tables and to Informations embedded in the Attachments.

Data shown in that data sheet are statistical values and might vary depending on the piece of product or the particular environment. Technical data and information are to the best of our knowledge at the time of printing. We exclude liability and do not accept responsibility for errors or for information which might be found misleading. Before using products in Alloy 24 we recommend that the customer should satisfy himself of their suitability. Our material expert is ready to support you.

Impressum

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Alloy 24 Availability of Productforms and Dimensions

Please check for actual availability of product forms and dimensions the website of Hempel Special Metals AG:

https://www.hempel-metals.com/en/metanavigation/downloads/

Attention has to be paid to the fact that the tables represent only one form of semi finished product, e.g. "Plates". Other product forms and dimensions are available on request.

Alloy 24 Fabrication Guidelines and Heat Treatments

General Remark on work-hardening Effects

With regard to the workability of Alloy 24, the work hardening behavior has been determined. Up to 40 % cold work the strengthening effect is in a comparable range to that of standard austenitic grades. For cold work of more than 15 % and also after hot working operations a subsequent annealing in the temperature range of 1120 - 1150° C with water quenching is recommended to ensure optimum corrosion resistance.

Cold Forming

Cold forming is well possible for Alloy 24. However, the much stronger strain hardening compared to unalloyed steels requires correspondingly higher forming forces. The strain hardening after cold forming of Alloy 24 is of a similar order of magnitude to other nitrogen-alloyed austenitic steels.

Machining

Due to the tendency to work hardening, *machining* must be carried out with tools made of high-quality high-speed steel (good cooling required) or, even better, with carbide tools. A large feed rate and a likewise larger cutting depth must be selected.

Hot Forming

Hot forming should take place in the temperature range between T max. = 1200°C and T min. = 900°C; cooling can take place in air. After such hot forming, a new solution heat treatment is mandatory.

Heat Treatments

Alloy 24 maintains excellent corrosion resistance and mechanical properties without need for post-weld heat treatment. However, after hot or cold forming, it may be desirable to solution anneal to remove stresses if stress corrosion cracking is a concern, such as in caustic or chloride environments.

If solution annealing is necessary, the heating cycle should be as prescribed by EN 10088-2 and/or ASTM A480 which specifies 1120- 1170°C (2050- 2140°F) followed by rapid cooling or water quenching. Typical heating times are 1-2 minutes per millimeter of thickness at the

annealing temperature, see Table 4
for a first orientation.

Table 4 - Heat Treatment

Hot working °C F	Cooling medium	Heat treatment °C F	Time	Cooling medium
1200- 900 2200-1650	air	1120-1170 2047-2137	15-30 min depending or thickness	**water**

Structure after heat treatment: austenite / face centered cubic (fcc)

Mechanical Surface Treatment

Mechanical surface treatments may be necessary for various reasons. Once to remove tarnish after welding or after heat treatment. On the other hand, a mechanical post-treatment can also be carried out for purely optical reasons to achieve a specific surface effect.

Chemical Surface Treatment

The pickling of stainless steels is often an absolute necessity in order to remove the scale layers formed during heat treatment or the annealing colours that form during welding.

The chemical surface finishing is either carried out in pickling baths or by means of pickling pastes. Pickling pastes are mainly used to remove tarnish after welding, i.e. partially. Entire constructions, containers etc. which have undergone heat treatment are pickled almost exclusively to remove the scale layers.

It is advisable to seek reassurance in this regard from the manufacturers of pickling and pickling pastes.

When pickling and passivating, the safety regulations for working with acids as well as the regulations for water and environmental protection must be observed. All current regulations and precautionary measures when handling these aggressive acids must be strictly observed! Nitric acid and especially hydrofluoric acid can cause severe physical damage (burns) and environmental damage if used improperly.

Electropolishing

Electropolishing, also called chemical polishing (shining), is particularly suitable for parts that cannot be polished mechanically (e.g. complicated parts, thin-walled constructions or parts that bend easily).During electropolishing, the parts are hung in a special bath. The parts to be polished are connected as an anode, which causes the surface to be metallically removed.

The execution of electropolishing should be entrusted exclusively to qualified specialist companies.

For “in-depth” information please visit our website. Downloads are available e.g.

- Alloy 24 – extended Material Datasheet including
- Fabrication Guidelines
- Welding Information and GTAW Recommendations
- Literature References

Alloy 24 Welding Guidelines / 1st Recommendations

The joining technology of nitrogen-alloyed stainless steels was tested and established successfully with the marine grades, e.g. Alloys 1.3964 and 1.3974 materials long before the development of Alloy 24 / 1.4565.

In principle, all common welding processes such as gas tungsten inert welding (TIG / GTAW), electrode welding (E), metal active gas welding (MAG) and submerged arc welding (UP) are fully applicable.

Modern welding techniques, e.g. laser welding without filler metal additions were successfully developed for extreme thin heat exchanger tubes. before considering electron beam welding, please consult our experts. The proper application of EBW depends amongst other factors on the composition of the chamber atmosphere.

Welding with the niobium-free, in molybdenum over-alloyed filler metal "Thermanit NiMo C" fulfils all development objectives. Neither a decrease in local corrosion resistance nor a reduction in mechanical values could be measured.

Due to restructuring within the Thyssen group, the successor company VOEST Böhler GmbH, Hamm is now the first point of contact for additional welding information. It must be noted, that other High Performance Alloy producers also offer adequate filler metals in their portfolio.

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