Duplex

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ACERINOX

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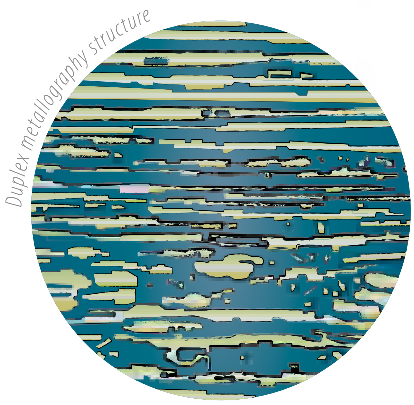
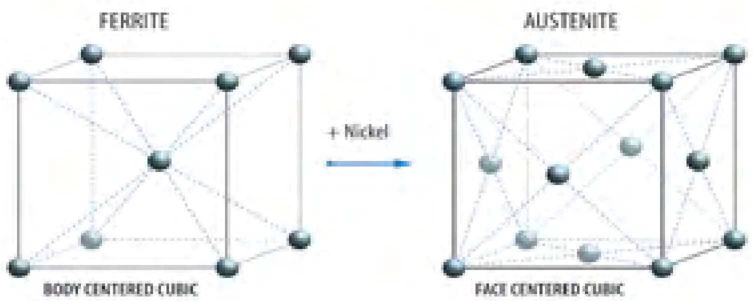
Introduction

Duplex stainless steels are a very interesting family of steels with a mixed structure compound of austenite and ferrite, both in similar proportions.





Chromium (body centred cubic structure) will stabilize ferrite, while nickel (face centred cubic structure) will stabilize austenite.

Physical properties of duplex are between austenitic and ferritic stainless steels.

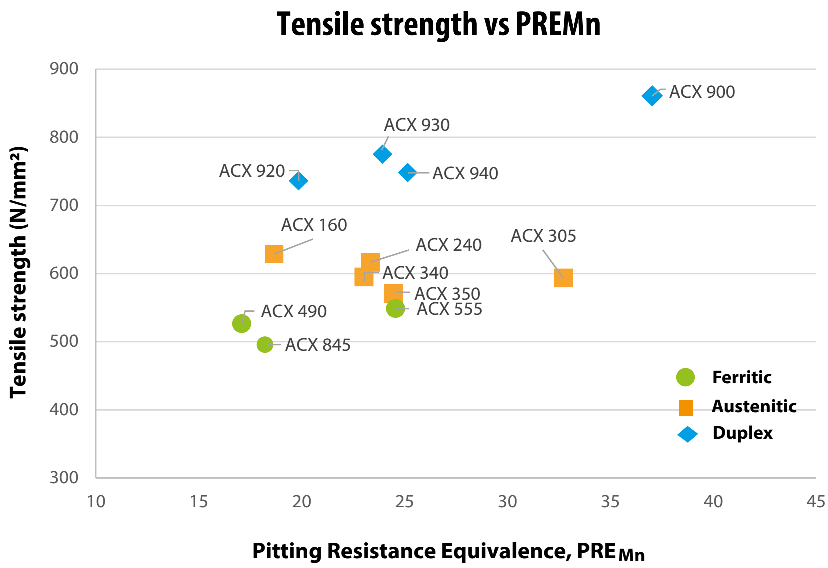
Chloride pitting and crevice corrosion resistance of stainless steel duplex will depend on the chromium, molybdenum, tungsten and nitrogen content. Duplex grades show more chloride stress corrosion cracking resistance than those of the 300-series austenitic stainless steels.

Finally, regarding their strength, it is higher than austenitic and ferritic's and they show good ductility and toughness.

Like any stainless steel, the alloying elements content will determine their performance on corrosion.

In order to give their specific properties to stainless steels, thermal treatments are carried out adapted to each family. In the case of austeno-ferritic (duplex) stainless steels, the hyper-temper process is intended to obtain a structure compound of 50% austenite and 50% ferrite, at room temperature, with no precipitation or/and intermetallic phases.

Duplex stainless steels are widely used in industry sectors such as storage and transport of energy, offshore structures or bridges construction due to their exceptional combination of high resistance and ease of fabrication, together with good resistance to a variety of corrosion types.



History

1920's
Description of the phase diagram of inon-chromium-nickel

1933
Sulfite peper industry
Castings produced in Finland

second world war

1960's
Nickel shortage

1968
AOD → N addition →
+HAZ toughness

1970
Super duplex Ferralium 255
weldability↓

1970 - 1980
Offshore gas & oil fields in the North Sea → Duplex 1.4462

1990's - 2000
Lean duplex

2000 - 2010
Super duplex
Hyper duplex

In 1927, E.C. Bain and W.E. Griffiths publish a paper with the phase diagram of iron-chromium-nickel entitled "An Introduction to Iron-Chromium-Nickel Alloys".

A few years later, in the early 30's, searching to reduce the intergranular corrosion problems of the paper industry, the first duplex grades are rolled in Sweden and duplex castings are produced in Finland. During the first generation of duplex stainless steels, some patents are also registered.

After the Second World War, they often use AISI 329 (1.4460) to make heat exchangers in contact with nitric acid. Later, those first generation duplex grades show good performance except for welding processes. The heat-affected zone (HAZ) of welds have low toughness because of the excessive ferrite, reducing resistance to corrosion.

In 1968, the invention of argon oxygen decarburization (AOD) process (stainless steel refining process), brings new stainless steel duplex grades. Nitrogen addition is one of the main achievements and this new second generation of duplex is defined by its nitrogen content. Soon after the first super duplex is produced.

In the 70's and 80's, due to the growing proliferation of oil and gas fields and offshore platforms, 2205 (1.4462) duplex is widely demanded. The high strength of this material allows reducing wall thickness, therefore total weight of the platforms.

At the end of 1990, a new grade called "lean" duplex appears due to the need of maintaining good mechanical properties in not such aggressive atmospheres. Their high nitrogen content stabilizes austenite and their low nickel content guarantees price stability. Following generations of duplex stainless steel follow developing as stainless steels do.

During the process in the AOD, samples are taken and the chemical composition is analysed in real time in the adjoining laboratory in order to fine-tune the elements to be added.

What makes them different?

The ferritic structure gives the chance of a cold deformation to rise mechanical properties while the austenitic part allows keeping the right ductility. Therefore, duplex grades keep the best characteristics of each family.

Their mechanical properties are very interesting. For example, yield strength is twice the austenitic's which make them perfect when structural calculation or developed solution lightening are is required.

Their correct resistance to corrosion, especially pitting, intergranular and stress cracking corrosion. This feature makes them an interesting choice in processes developed in harsh conditions.

Good wearing and abrasion resistance however, it is not up to martensitic or ferritic stainless steels.

Excellent cyclic loading and fatigue strength.

Their least nickel content implies greater price stability. This less dependence on fickle elements, subject to speculation, makes them a good option for long-term projects, as civil works.

Duplex steels are weldable with the necessary changes and adaptations mentioned in this catalogue

Ferrite content gives duplex steels their magnetic character.

Their lower coefficient of thermal expansion than austenitic steels facilitates their application in complex shaping.

Similar Thermal conductivity to that of austenitic stainless steels.

Duplex

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Once the metallurgical process has ended, the material is delivered to the cutting lines to adapt its size to our customers' needs. The coil may be cut longitudinally to give strips of any width, transversely for sheets, or in circles or flat bars. Then the material undergoes a new inspection.

Grades. Equivalences

As a result of innovation and development, in Acerinox we present the following grades of duplex, which adapt to the situations that may arise.

ACERINOX	EURONORM		ASTM	UNS
ACX 900	EN 1.4462	X2CrNiMoN22-5-3	ASTM 2205	S31803 / S32205
ACX 920	EN 1.4482	X2CrMnNiMoN21-5-3	ASTM 2001	S32001
ACX 930	EN 1.4162	X2CrMnNiN21-5-1	ASTM 2101	S32101
ACX 940	EN 1.4362	X2CrNiN23-4	ASTM 2304	S32304

Chemical composition

	C	Si	Mn	P	S	Cr	Ni	Mo	N	Cu
ACX 900	≤0.03	≤1	≤2	≤0.030	≤0.015	22-23	4.5-6.5	3.0-3.5	0.14-0.2	-
ACX 920	≤0.03	≤1	4-6	≤0.025	≤0.03	19.5-21.5	1.5-3	≤0.6	0.05-0.17	≤1.0
ACX 930	≤0.04	≤1	4-6	≤0.025	≤0.015	21-22	1.35-1.7	0.1-0.8	0.2-0.25	≤0.5
ACX 940	≤0.03	≤1	≤2	≤0.025	≤0.015	22-24.5	3.5-5.5	≤0.6	0.05-0.20	0.1-0.6

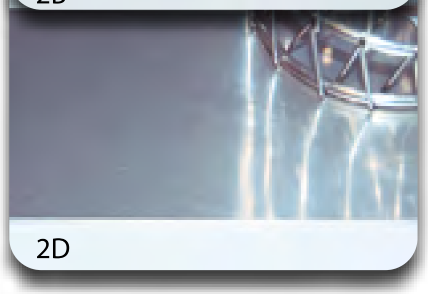
Product. Size. Finish

HOT ROLLED			
	THICKNESS ** (mm)	**WIDTH (mm)**	**LENGTH (mm)**
COIL	4.0 - 8.0*	915 - 1555	-
PLATE	10 - 50.8	915 - 1524	2000 - 12000

COLD ROLLED				
	FINISH	**THICKNESS ** (mm)**	**WIDTH (mm)**	**LENGTH (mm)**
COIL	2D / 2B	0.5 - 4.0	all	-

* *Untrimmed maximum gauge*
** *In case of laser cutting, flatness specifications cannot be guaranteed for gauges 2-10 mm*


2B


2D

Specifications & tolerances

Acerinox Europa supplies duplex stainless steels according to the following specifications:

EN 10088-2	EN 10028-7	ASTM A-240

Mechanical properties

Duplex stainless steels have exceptional mechanical properties. Their yield strength at room temperature in the solution annealed conditioned is more than double that of standard austenitic stainless steels with no nitrogen. This allows the wall thickness reduction in some applications, therefore structures and equipment weight reduction.

According to EN 10088-2 & EN 10028-7	**Tensile strength Rm (MPa) N/mm²**			**Yield stress $Rp_{0.2}$ (MPa) N/mm²**			**Elongation (%)**		
	C	**H**	**P**	**C**	**H**	**P**	**C**	**H**	**P**
ACX 900	700-950	700-950	640-840	≥500	≥460	≥460	≥20	≥25	≥25
ACX 920	700-900	660-900	650-850	≥500	≥480	≥450	≥20	≥30	≥30
ACX 930	700-900	600-900	650-850	≥530	≥480	≥450	≥20	≥30	≥30
ACX 940	650-850	650-850	630-800	≥450	≥400	≥400	≥25	≥25	≥25

C = cold rolled sheet	*H = hot rolled sheet*	*P = plate*

Depending on the thermal treatment applied to balance ferrite and austenite proportion, their performance will vary according to the predominant structure.

Physical properties

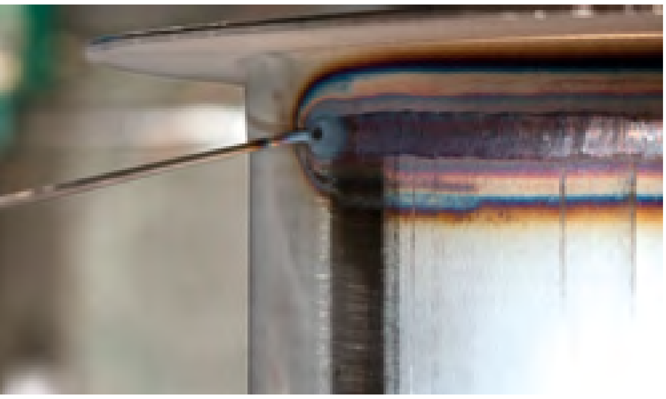
		ACX 900	**ACX 920**	**ACX 930**	**ACX 940**
Density (kg/dm³)	20ºC	7.8	7.8	7.7	7.8
Modulus of elasticity (GPa)	20ºC	200	200	205	200
	100ºC	194	194	200	190
	200ºC	186	186	190	180
	300ºC	180	180	180	170
Specific heat (J/kg K)	20ºC	500			
Thermal conductivity (W/m·K)	20ºC	15	15	15	16
	100ºC	-	16	-	17
	200ºC	-	-	-	19
	300ºC	-	-	-	20
Electrical resistivity (Ω·mm²/m)	20ºC	0.80	0.80	0.75	0.80
Mean coefficient of linear expansion between 20ºC (10^{-6}x K^{-1}) and	100ºC	13	13	13	13
	200ºC	13.5	13.5	14	13.5
	300ºC	14	14	14.5	14

Thermal processing & fabrication

FERRITE/AUSTENITE STRUCTURE*

Fe-Cr-Ni phase diagram is a map of the metallurgical behaviour of duplex stainless steel. The relative content of ferrite and austenite in the processed material depends on the composition and thermal history of the grade of steel. Slight changes in the composition can affect the relative volume fraction of the two phases.

The balance of phases is achieved adjusting Cr, Mo, Ni and N, and controlling the thermal history.



Because cooling time determines the ferrite content that can be transformed in austenite, after heat temperature expositions, the cooling rate impacts on phases balance.

Due to high cooling rates favour ferrite retention, it is possible to have more ferrite than that of the balance. For instance, low heat input welding in a heavy section could cause excess of ferrite at the HAZ, Heat Affected Zone.

EN 1.4462 (2205)	
Solidification range	1470 - 1380 ºC
Scaling T in air	1000 ºC
Sigma phase formation	700 - 950ºC
Carbide precipitation	450 - 800ºC
475ºC Embrittlement	300 - 525ºC

Typical temperatures for precipitation reactions and other characteristic reactions in duplex stainless steel 2205 (EN 1.4462)

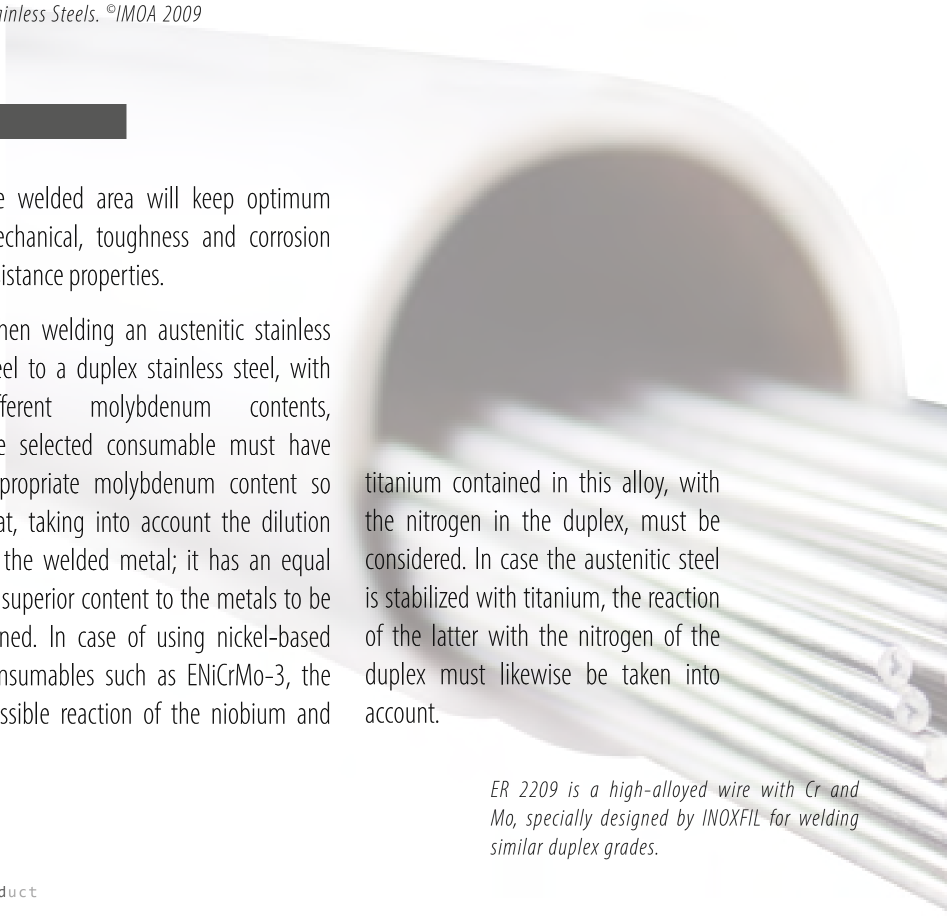
* *Practical Guidelines for the Fabrication of Duplex Stainless Steels. ©IMOA 2009*

WELDING**

ACX 900, ACX 920, ACX 930 and ACX 940 duplex stainless steels can be welded using most of the conventional welding methods, such as MMA/SMAW, TIG, MIG, SAW, FCAW, laser, etc. Due to its two-phase structure, it is resistant to hot cracking, grain coarsening embrittlement and martensite formation.

The use of nickel-enriched filler material and specific process conditions for a controlled cooling are required to obtain welding with correct micro-structural and chemistry balances. Therefore, the welded area will keep optimum mechanical, toughness and corrosion resistance properties.

When welding an austenitic stainless steel to a duplex stainless steel, with different molybdenum contents, the selected consumable must have appropriate molybdenum content so that, taking into account the dilution of the welded metal; it has an equal or superior content to the metals to be joined. In case of using nickel-based consumables such as ENiCrMo-3, the possible reaction of the niobium and titanium contained in this alloy, with the nitrogen in the duplex, must be considered. In case the austenitic steel is stabilized with titanium, the reaction of the latter with the nitrogen of the duplex must likewise be taken into account.



ER 2209 is a high-alloyed wire with Cr and Mo, specially designed by INOXFIL for welding similar duplex grades.

Heat input and inter-pass temperatures

Duplex steels may tolerate higher heat inputs than austenitic steels. To ensure that optimal properties are obtained for duplex steels, heat should be maintained between::

LEAN DUPLEX	0.5 - 2.5 kJ/mm
STANDARD DUPLEX	1.75 - 2.0 kJ/mm
SUPER DUPLEX	1.5 - 1.75 kJ/mm
HYPER DUPLEX	0.2 - 1.0 kJ/mm

With the correct heat input and cooling, the structure of a duplex weld resists hot cracking better than austenitic steel weld structure. Duplex stainless steels have higher thermal conductivity and lower coefficient of thermal expansion than austenitic stainless steels, so high stresses do not result due to heating through welding.

Therefore, while embrittlement is not severe and stresses are low, hot cracking does not usually constitute a problem for duplex. To avoid problems at the area affected by heat, welding procedure should allow fast cooling (not extremely fast) of this area. The initial temperature of the piece to be welded is important because the mass of the piece itself should provide the correct cooling of the area affected by the heat. Normally, the maximum inter-pass temperature is limited to:

LEAN DUPLEX	250ºC
STANDARD DUPLEX	150 - 250ºC
SUPER DUPLEX	100 - 150ºC
HYPER DUPLEX	100ºC

Post heat treatment

Stress relief after duplex steel welding is not necessary, and could even be harmful because the heat treatment can precipitate intermetallic phases between 700-1000ºC or the formation of alpha prima (α') at 475ºC, with loss of toughness and corrosion resistance. Post welding treatment higher than 315ºC, may negatively affect toughness and corrosion resistance of duplex steels.
Any post welding heat treatment should include complete solubilisation annealing, followed by water tempering. Solubilisation annealing should be considered after autogenous welding (without consumable), since the micro-structure will be highly ferritic if a high alloy filler metal is not used.

Dureza

LEAN DUPLEX	≤30 HRC
STANDARD DUPLEX	≤31 HRC
SUPER DUPLEX	≤32 HRC
HYPER DUPLEX	34-36 HRC

Standard values

Duplex steels are high strength alloys, which can only be made with certain hardness. Hardness limits are established to avoid stress cracking.

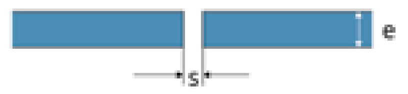
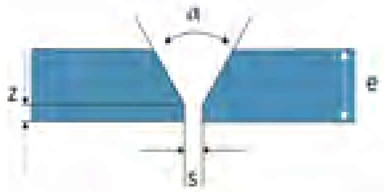
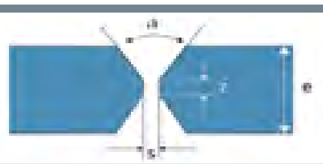
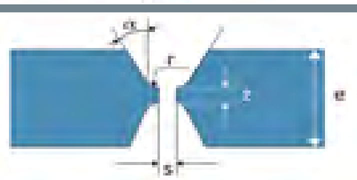
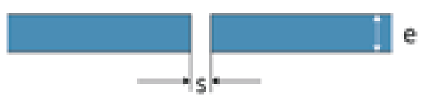
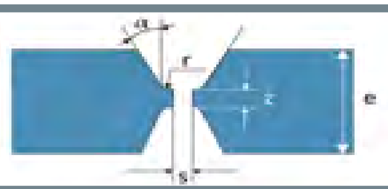
Precautions

It is advisable to limit the heat input. In general, before and after heating is not necessary and it is convenient to take into account:

1. Grain growth in the heat affected area above 1100ºC. In order to avoid this we use steels with higher austenite content, according to the application.
2. Precipitation of chromium carbides in the heat affected area. It will depend on the carbon content.
3. Sigma phase formation at a temperature will depend on the chromium content and will be formed when slow cooling (more than 2 or 3 minutes at 900ºC).

Joint design

Duplex steels require joint preparation with a design that allows good penetration and avoids the lack of consumable input in the welding. In comparison with standard austenitic steel, with the same parameters, welder would observe lower penetration and lower bath fluidity; in order to compensate this and to facilitate penetration the angle should be about 10º bigger, smaller bead and bigger root separation. It is better mechanizing than grinding for joint preparation and to provide uniformity in thickness and edge separation.

Type of joint	Process	Thickness e (mm)	Separation s (mm)	Root face z (mm)	Bevel α (º)
	GTAW	3-5	1-3	-	-
	GMAW	3-6		-	-
	SMAW	3-4		-	-
	SMAW	4-15	1-3	1-2	55-65
	GTAW	3-8			60-70
	GMAW	5-12			
	SAW	9-12	0	5	80
	SMAW	>10	1.5-3	1-3	55-65
	GMAW				60-70
	SAW		0	3-5	90
	SMAW	>25	1-3	1-3	10-15
	GMAW				
	SAW		0	3-5	
	GTAW	>3	0-2	-	-
	GMAW			-	-
	SMAW			-	-
	SMAW	3-15	2-3	1-2	60-70
	GTAW	2.5-8			
	GMAW	3-12			
	SAW	4-12			70-80
	SMAW	12-60	1-2	2-3	10-15
	GTAW	>8		1-2	
	GMAW	>12		2-3	
	SAW	>10		1-3	

*** Welding and cutting of stainless steels ©CEDINOX 2018*

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In the case of austenitic stainless steel, an experienced welder may overcome the deficiencies in joint preparation with torch handling. In the case of duplex stainless steel, this handling may cause excessive joint heating and may reach a harmful temperature that may cause results outside the qualified procedure.

Some recommendations

Transport & handling

Before shipping, make sure every chain and steel element is not in contact with stainless steel rebar. Raffia or wooden elements must be used at possible contact places.

When outside storage is required, material should be covered by a waterproof canvas.

Avoid contact with the ground using wooden blocks and store stainless steel and carbon steel separately. This way we avoid problems with contamination by oils, dirt or by contact among different materials.

Avoid carbon steel slings, use nylon or polypropylene ones wherever possible.

When stainless steel has to be moved with lift trucks, the forks should be protected with nylon.

Manufacturing & installation

Make sure stainless steel is contamination free before starting to work. If there is any, it will be removed by pickling or mechanical means (*).

If cleaning is required, do it with pressurized water. Do not use sea or brackish water.

All tools employed in the installation must be made of stainless steel and these should have been never used with carbon steel. If this is not possible, tools must be carefully cleaned before use.

Stainless steel should be processed in machines exclusively dedicated to this material, in order to avoid contamination by projections or oxide traces from other materials.

Excessive temperature oxidation or *blueing* due to abrasive cutting, should be removed with pickling paste. Good refrigerated cutting tools help to avoid the problem..

Whether, for any reason, the surface is painted, you need to prime/prepare the surface by acid pickling or abrasion. Follow the instructions of the paint manufacturer.

(*) Contact your supplier

Surface maintenance

Regular cleaning is mandatory to keep unaltered surfaces indefinitely and obtain the best performance of stainless steel.

For cleaning, it is recommended the use of water and neutral soap applied with a soft cloth or brush that do not scratch the surface. To finish, always rinse with plenty of water to remove any trace of the cleaner.

Chloride products must be avoided. In case of use, the contact must be minimum and must be followed by a thorough rinse with plenty of water.

More information about stainless steel cleaning through this code:

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Sited in Campo de Gibraltar, Acerinox Europa has its own seaport in a privileged location that guarantees the material movement, as the reception of raw materials as finished products ready to be delivered to destination.

Corrosion resistance

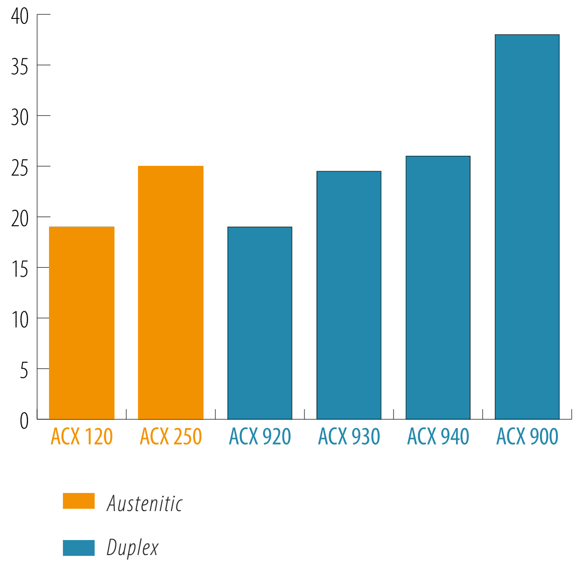
In general, the high chromium content of duplex stainless steel grants good corrosion resistance. Chromium, molybdenum and nitrogen contents give ACX 900 (1.4462) excellent corrosion resistance, the performance of ACX 940 (1.4362) and ACX 930 (1.4162) towards corrosion is comparable to ACX 250 (1.4401) and ACX 920 is similar to austenitic stainless steel ACX 120 (1.4301).

Pitting corrosion

It occurs in a localized zone at the surface of the steel. This type of corrosion causes de local destruction of the passive layer necessary to induce pitting. Certain circumstances can promote this type pitting corrosion such as T and chloride concentration.

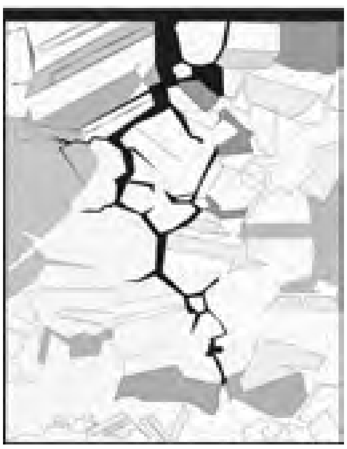
In order to relate the resistance of stainless steels of the same family to it, Pitting Resistance Equivalent Number, PREN*, can be used. It establishes the theoretical relationship between stainless steel's composition and its relative pitting resistance.

*PRE_{Mn} = %Cr + 3,3%Mo + 30%N - %Mn



Stress corrosion cracking

A sudden crack appears in tensioned parts without previous indicators or signals. Crack often develops slowly on the inside but when it comes out it is normally irreversible. Aggressive environments such as high temperature and high chloride concentration, help to develop this phenomena.



ACX 900, ACX 920, ACX 930 and ACX 940 are not as susceptible as austenitic grades towards this type of corrosion due to their bi-phase structure that does not help the stress propagation.

General corrosion

Corrosion rates <0.1 mm/year in contact with:

	ACX 900	ACX 920	ACX 940
Acetic acid	100%, 80ºC	20%, 80ºC	50%, boiling T
Formic acid	90%, 10ºC		
Phosphoric acid	86%, 85ºC	20%, 60ºC	20%, boiling T
Nitric acid	65%, 70ºC	20%, 50ºC	
Sulphuric acid	30%, 20ºC		20%, room T
Tartaric acid	70%, boiling T		
Sodium hydroxide	30%, 100ºC		

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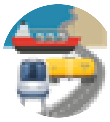
ACX 900 shows good behaviour in most of atmospheres. In marine environment, their performance is better than ACX 250 (1.4401).

Some projects & applications



Chemical tankers.

Tanker trucks.

Iron wagons
in Kiruna, Sweden.

Trams
(i.e.: Sâo Paulo, Brazil).

Ships (hull, jib,
propeller, mast).

Pressure valves.

Heat exchangers.

Condensers.

Storage.

Distillation towers.

Ancillary equipment.

Digestors.

Alcohol tanks.

Paper industry.

Louvre Museum,
Abu Dhabi (dome).

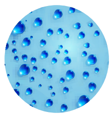
Louis Vuitton Foundation.
Paris, France.

Congress Centre in Stockholm
(façade).

Doha airport, Qatar (roof).

La Sagrada Familia.
Barcelona, Spain.

Queensway tunnel,
under Mersey river, UK.



Tanks.

Water treatment plants.

Drinking water tanks.

Desalination plants.

Heaters.

Effluent treatments.

Desulphurization equipment.

Ancillary equipment
(pumps, valves,
fittings, filters).

Off-shore pipelines, platforms.

Sluicegates in Slussen,
Stockholm, Sweden.

Sluicegates at Gårda Dämme
in Gothenburg, Sweden.

Sluicegates at Mont Saint
Michel, France.

Helix bridge, Singapore.

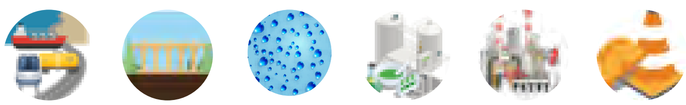
Bascule pedestrian bridge
in Lyon, France.

Trumpf footbridge in
Ditzingen, Germany.

San Diego harbour bridge
in California, USA.

Tsunami-proof floodgates
in Kamihirai, Japan.

New Farm footbridge
in Brisbane, Australia.



Transport | Civil works | Water | Chemical/ Paper | Oil&Gas | Construction

Duplex stainless steels are used in a wide and varied range of projects. These are some of them. Applications that we want to highlight made with stainless steel from different producers around the world.

Duplex
Beyond Excellence

Our society demands continuous technological developments that require constant research and expertise knowledge to solve, not only today's challenges but ensure a sustainable future ahead.

Certificates

Complete information on Acerinox Europa certificates:

ESG ratings:

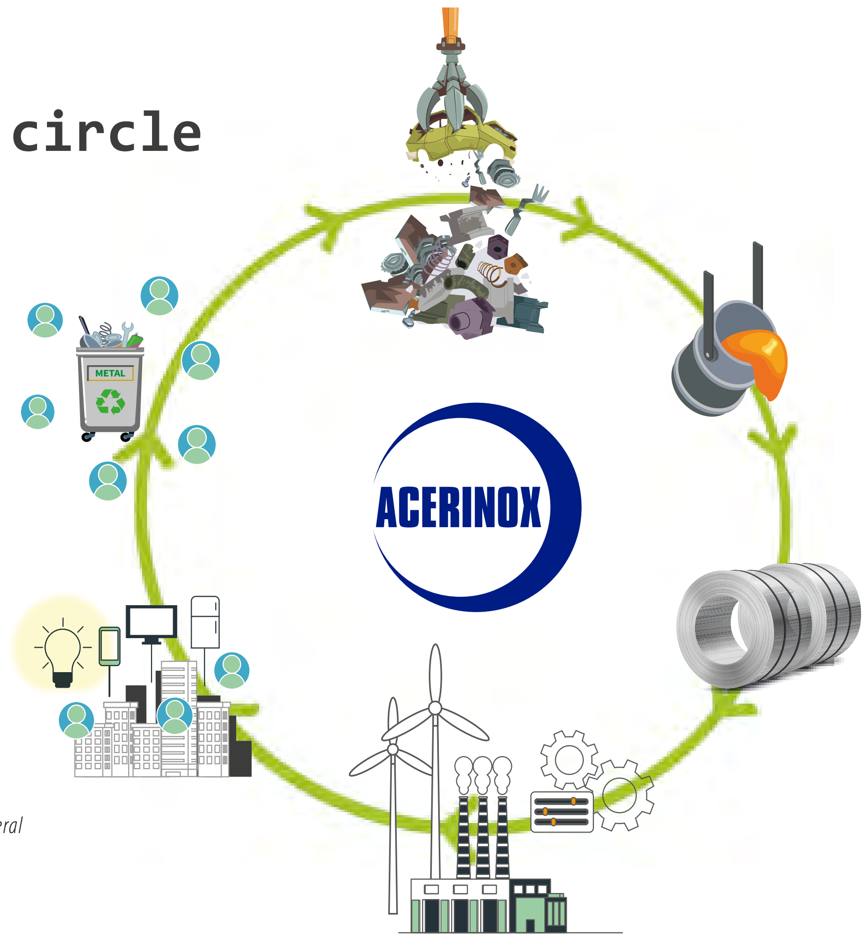
Collaboration with organizations:

Sustainable circle

"Acerinox uses more than 90% recycled materials to produce stainless steels and high performance alloys that are durable and eternally recyclable without losing their characteristics. By recovering our waste, of which we already recycle more than 80%, we are without a doubt the paradigm of the circular economy.

*We efficiently manufacture stainless steels and high-performance alloys with a respectful approach and we are committed to a responsible management model that helps protect the planet, reduce inequalities, and promote a more prosperous and sustainable world."**

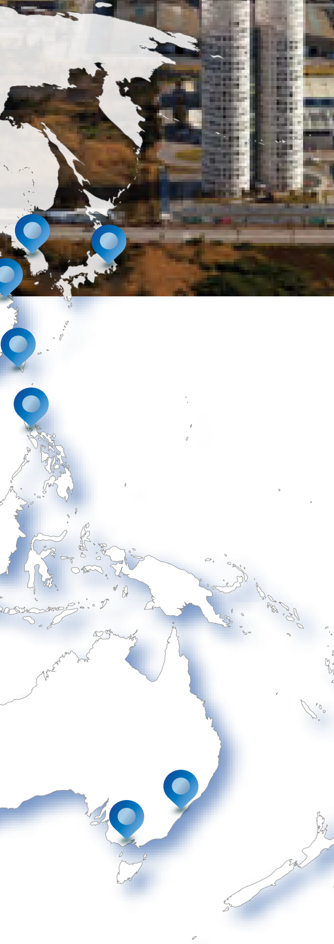
**Chief Executive Officer's. 2024 Annual General Meeting Report*



Dúplex
Beyond Excellence

Acerinox Group has the commitment to contributing to the achievement of the Sustainable Development Goals (SDGs) approved by the United Nations, particularly via manufacturing entirely and endlessly recyclable products, while also promoting innovation, education, equality policies and fight against climate change.

Acerinox: the confidence of a strong group



Acerinox Group is global leader in the manufacture of stainless steel and high performance alloys. We have factories with 3.5 million tonnes of melting shop capacity per year. Acerinox Europa, North American Stainless and Columbus Stainless manufacture flat product and Roldán, Inoxfil and NAS are long product producers. VDM Metals, worldwide leader in the fabrication and design of high performance alloys, is part of the Group from 2020. In November 2024, Acerinox completes the acquisition of Haynes International, U.S. leading manufacturer and marketer of technologically advanced high-performance alloys.

The factories and centres of Acerinox Group meet quality and environment controls according to the specific regulations of each country and to Environmental Management Systems. Our subsidiaries also exceed the requirements of the legislative demands in different areas such as quality, security or environment. We work in 79 countries to build a more sustainable society, meeting present and future needs thanks to our durable, hi-performance and respectful materials.

Acerinox Europa was the first integrated stainless steel factory in the world. Founded in 1970, the plant continues at the forefront as one of the most advanced factories in the sector thanks to a continuous investment policy.

With its own cargo seaport, Acerinox Europa is in a privileged location next to the straits that link the Atlantic with the Mediterranean.

With a melting shop capacity of one million tonnes, Acerinox Europa supplies mainly flat products to the European continent and material for producing long products to other plants within the Group.

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ACERINOX

www.acerinox.com

ACERINOX EUROPA

ROLDAN S.A.

INOXFIL

COLUMBUS STAINLESS [Pty] Ltd

NAS

VDM Metals

HAYNES International