POLITECNICO DI TORINO

Laurea Magistrale in Ingegneria Meccanica (LM-33)

Tesi di Laurea Magistrale

Stainless Steels for Aseptic and Antimicrobial Applications

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April 2021

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INTRODUCTION

In completing normal activities linked to his own existence, man lives in touch with a good range of steels which are the results of a thousand-year evolution and constant research. When talking about stainless steel, a preconception is created of a noble, expensive and, above all, intended for very specific applications, that it requires unaltered aesthetic appearance and excellent resistance to corrosive phenomena. The tendency, in recent years, is instead to think about this material altogether its multiple aspects and not only as a "noble metal" that resists corrosion; physical and mechanical characteristics are therefore exploited specifically.
This is why stainless steels are considerably increasing their presence in certain sectors which, until recently, were considered to belong exclusively to traditional materials like carbon steels. In recent years, there has been a big increase within the application of stainless steel in all industry segments, so not only where high corrosion resistance and surface quality are necessary, but also in structural parts, where the mechanical properties are needed: yield strength, elongation at break, resilience. The trend for the following years is to continue expanding the consumption of Stainless Steels, due to the versatility of this material and its capacity of being recycled.

1.1 Steel Making Process

Producing Stainless Steels is not an easy task, and needs a lot of technology and science because, manufacturers must determine complex parameters and look into the future to the application of the material, since the slight modification in the process, can result in complex modifications into the metallurgy of the steel. There are many customers and Stainless Steel users around the globe, however there are very few professionals that understand deeply the metallurgy and complexity involved in the production of these grades [10].

Considering what was mentioned, these are the main processes involved in the Stainless Steels Production and each one of them is controlled accordingly to the final application [11]:

- Reduction Process.
- Melt Shop Process.
- Hot Rolling.
- Annealing.
- Pickling.
- Cold Rolling.
- Finishing Stage.

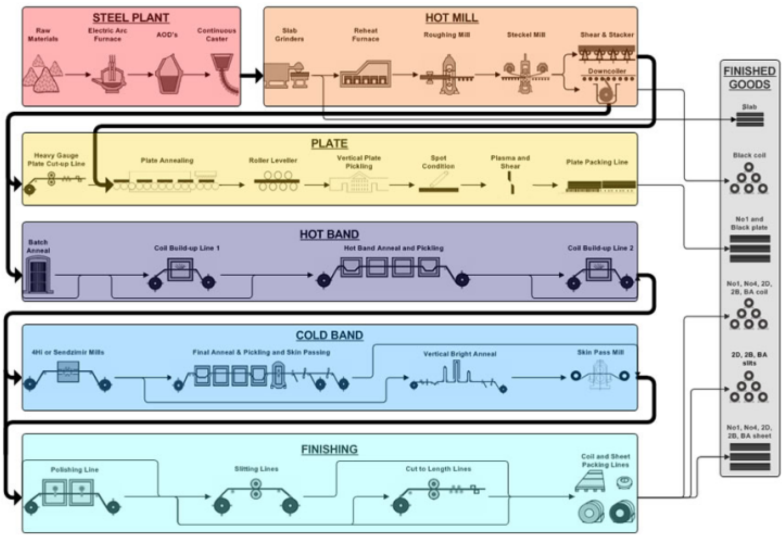


Figure 1.1: A schematic diagram of Stainless Steel Making Process

1.1.1 Reduction Process

The first step of steel making is the reduction process, where the main target is to reduce the iron ore to a metallic phase, using a reducing environment (often provided by carbon monoxide gas) that will react with the ore, driving off the oxygen and leaving the Fe.

The final product of the reduction process is "Pig iron" which is an intermediate product of the industry within the production of steel, also referred to as crude iron with a very high carbon content, typically 3.8 - 4.7%, along side silica and other slag constituents, which makes it very fragile and indirectly useful as a cloth, apart from limited applications.

- **Direct reduction**

The direct reduction process is employed to convert ore into metal iron using reducing gases within the other way to the flow of solid material within a mobile bed furnace producing directly reduced iron (DRI). If the cooling phase is omitted, the DRI are often immediately briquetted in hot iron (HBI). The reducing gas could also be generated outside the reduction furnace or could also be generated from hydrocarbons introduced into the reduction zone of the furnace.
The mixture is skilled the method heater to get most of the specified temperature then the oxygen is injected into the transfer line just before the reactor, so as to extend the temperature of the reducing gas to the extent required for in-Reformation and reduction within the reactor.
Partial oxidation and pre-reforming reactions of gas with oxygen are administered within the transfer line, producing reducing gases (H_2 and CO). Once in touch with the solid material inside the reactor, further cracking and reforming reactions are administered thanks to the catalytic effect of metallic iron [40]:

$$CH_4 + 1/2O_2 \rightarrow CO + 2H_2$$
$$O_2 + 2H_2 \rightarrow 2H_2O$$
$$CH_4 + H_2O \rightarrow CO + 3H_2$$
$$CO_2 + H_2 \rightarrow CO + H_2O$$

Oxygen is faraway from ore by chemical reactions supported hydrogen (H_2) and carbon monoxide gas (CO) for the assembly of highly metallised DRI:

$$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$$
$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

The operating conditions of the method are characterized by heat and high pressure. Additionally, the practice of coating the pellets with a skinny layer of cement or lime, before loading them into the vat furnace, prevents bonding problems and also helps to scale back the generation of ends within the reduction process.
The process is characterised by the elimination of the by-products of the reduction process, namely H_2O and CO_2. Especially, the selective elimination of CO_2 through

chemical absorption is very efficient and energy-efficient thanks to the high operating pressure of the plant. CO_2 selectively faraway from the method gas stream are often used for other applications or sequestered. [40]

- **Blast Furnace**

The blast furnaces that are being used in steel production nowadays are a large component, usually manufactured by steel and refractory materials that can be composites or special steels, and they are usually high cylindrical structures.
Iron ore, coke (or charcoal in some cases) and limestone ($CaCO_3$) are the basic materials fed into the furnace from the top and they sink down to the bottom of the structure, getting hotter as they go.
In the medium area of the blast furnace, gas obtained from the combustion of the coke (or charcoal) captures oxygen from the iron ore.
Finally, in the bottom of the furnace, limestone reacts with the impurities forming what is known as slag [42].

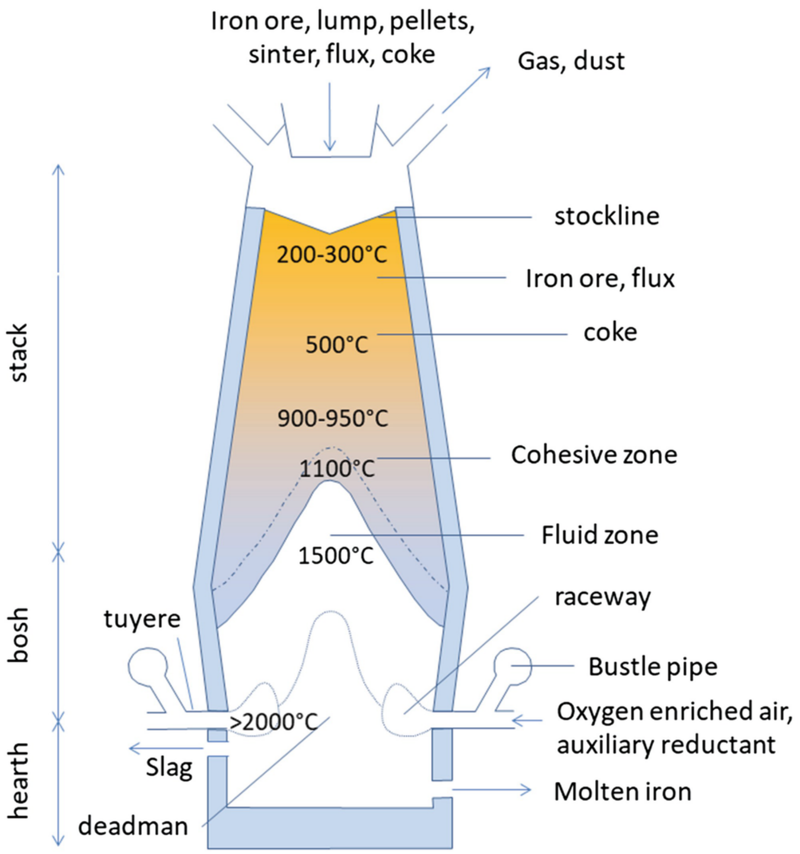


Figure 1.2: A schematic diagram of Blast Furnace

- **Electric Arc-Furnace Melting**

The melting process starts at low voltage between the electrodes and therefore the scrap; the arc during this era is unstable and so as to enhance the arc stability small pieces of the scrap are placed within the upper layer of the charge. The electrodes descend by melting the charge and penetrating the scrap formation holes after which the molten metal flows to rock bottom of the furnace. When the electrodes reach the liquid bath the arc becomes stable and therefore the voltage are often increased and the electrodes rise together at the melting level. About 85% of the scrap melts during this era and the arc temperature reaches 3500 °C.
Scrap buckets shall be loaded in such how on make sure that the heavy scrap is cushioned when the load falls on the fireside so as to realize good electrical conductivity within the charge, a coffee risk of electrode breakage and good protection of furnace walls during melting. Sometimes coals and slag trainers are added to the charge to stop overoxidation of steel and to accelerate the formation of slag. After melting, the carbon level within the steel is about 0.25% above the ultimate tap level, which prevents over-oxidation of the molten material. The carbon content of the steel is reduced by oxygen blowing or increased by carbon injection.
Iron oxide causes increase of Oxygen content within the molten steel consistent with the reaction:

$$FeO \rightarrow Fe + O$$

Oxygen dissolved within the melt oxidizes carbon, phosphorous, silicon and manganese:

$$C + O \rightarrow CO$$
$$Si + O_2 \rightarrow SiO_2$$
$$Mn + \frac{1}{2}O_2 \rightarrow MnO$$
$$2P + \frac{5}{2}O_2 \rightarrow P_2O_5$$

Carbon monoxide partially burns within the atmosphere:

$$CO + O_2 \rightarrow \frac{1}{2}CO_2$$

Samples are taken, the temperature is checked, additions are made and, when all conditions are correct, the furnace is tapped by rotating it forward in order that the steel flows over the spout or through the vertical casting hole during a ladle. When the slag appears, a fast back inclination is applied and therefore the slag is poured through the rear door of the furnace into a slag pot. [41]

1.1.2 Melt Shop Process

The Melt Shop process is a crucial stage where the chemical composition of the steel will be defined and the material will be transformed from the liquid phase to the solid phase. It's a very dangerous environment so safety must be the priority number 1 of workers, these are the main risks involved: high temperatures, dust, noise, fire, suspended loads, confined spaces and electricity.
The production and casting process are often divided into three distinct phases: primary steelworks, secondary steelworks and casting. The first steelworks concerns the assembly of liquid steel, which is subsequently refined both for its composition and for its purity through a series of secondary steelworks processes. The molten steel with the specified composition, cleaning and temperature is finally transformed into solid products through casting [12].

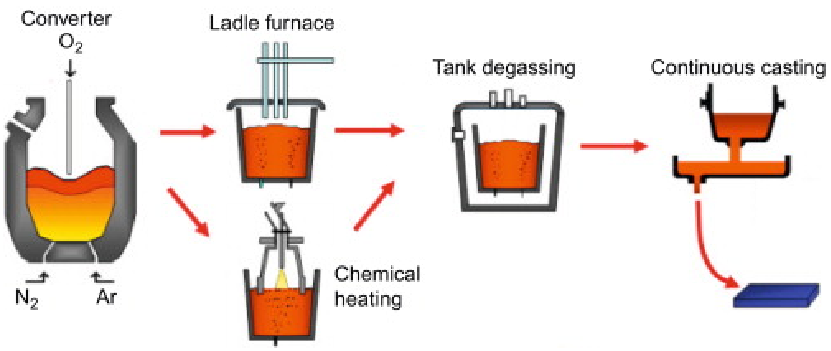


Figure 1.3: Melt Shop Process

The Molten Steel follows several stages of processing:

- **Decarburization.**

Decarburization is a metallurgical process in which the surface of the steel is depleted of carbon by heating above the lower critical temperature or by a chemical process. This process is usually beneficial or harmful, relying on the appliance that the metal are getting to be used; it's therefore either something which can be done intentionally as a stage during a producing process, or something that happens as a side effect of a process and must be prevented.
During decarburization, carbon spreads from the surface of the metal, thus weakening the metal; this diffusion increases at higher temperatures. The effect of decarburization not only lowers the resistance, but also increases the shear tension below the surface of the metal, fatigue resistance decreases, while the expansion rate of cracks and therefore the rate of wear and tear increase. As the carbon content decreases during decarburization and therefore the steel surface features a reduced amount of hardness, decarburization can improve machinability and another effect

that would occur is best formability on the steel surface.
It's possible to divide decarburization into three phases: the reaction to the surface, the interstitial diffusion of carbon atoms then the dissolution of carbides inside the steel.
Decarburization usually starts around 700 °C, and therefore the carbon on the surface reacts with oxygen or hydrogen and spreads. When steel is delivered to this temperature and exposed to gases like hydrogen and oxygen, the carbon of steel binds to those gases and leaves the steel with a reduced amount of carbon. Since gases are only in touch with the steel surface, decarburization generally occurs more heavily on the outer layers of Steel; carbon from the within spreads towards the surface, passing from high to low concentration and continues until it reaches the utmost depth of decarburization. Note that carbon diffusion rates are influenced by both temperature and composition.
Stainless steel contains highly oxidable additives, like chromium and molybdenum and may only be decarburized by reacting with dry hydrogen, which has no water content. [35] It is important to understand the decarburization process of varied kinds of steel during heat treatment and hot processing operations because compositions of varied alloys can also greatly influence the decarburization response of a selected kind of steel. Therefore, it is vital to review not only the effect of temperature on the decarburization depth, but also the effect that stable carbide formation and additional alloy elements wear the decarburization response of a selected alloy [13].

- **Ladle steps.**

The functions of a ladle furnace are:
- Heating of liquid steel by electricity from graphite electrodes.
- Homogenisation of steel temperature and chemistry by noble gas rinsing.
- Formation of a slag layer.
- Addition of iron alloys to supply chemical control bulk or trim.
- Addition of carrot threads for trimming and morphological control.
- Provide a way for deep desulphurisation.
- Provide a way for dephosphorization.
- Acts as a buffer for downstream equipment and processes.

Liquid steel are often heated by oxidizing aluminium and/or silicon by injection of oxygen through a lance; in some steelworks the steel is heated within the ladle by submerged oxygen injection.
The simplest sort of steel treatment within the ladle occurs when the blending effect of the casting current is employed to feature deoxidants, slag formers, and little amounts of alloying agents; these materials are placed within the ladle before tapping or injected into the tapping flow.
Additions are usually made to the stirring station by a wire feeder; another treatment is powder injection. In this treatment the metal powder is injected by a lance

deep into the liquid steel after being fluidized by the argon in a pressure vessel.
Exposure of steel to vacuum features a profound effect on all metallurgical reactions involving gases; there are differing types of vacuum treatment, their use depends on the standard of the steel and therefore the required production rates. When degassing into a ladle, the effectiveness of degassing decreases as you descend into the molten steel bath because the lower steel layers are much less suffering from vacuum as these layers are under the influence of ferrostatic pressure thanks to the liquid steel column; so bath agitation would help expose the whole molten steel content to vacuum.
A modification of the tank's degassing device is that the vacuum oxygen decarburizer (VOD), which has an oxygen lance within the center of the tank cover to enhance the removal of vacuum carbon; VOD is employed to lower the carbon content of high alloy steels without even overoxidizing such oxidisable alloy elements as chromium.
There also are tank degassactors that have electrodes installed as a ladle furnace, thus allowing arc heating under vacuum; this process is named vacuum arc degassing, or VAD. The key feature within the Argon oxygen decarburization (AOD) process is that oxygen for decarburization is mixed with inert argon or nitrogen and injected through submerged tuyeres. [14; 15]

- **Continuous Casting Operation.**

The continuous casting process may be a very effective method for the manufacture of semi-finished products like steel bars, profiles, slabs, strips and tubes.
The casting temperature is about 1400 °C; the molten metal is poured continuously into a storage vessel called a ladle and from there flows into a vertical or horizontal casting mould with open end. Because it flows through the mould, which is cooled with water, the liquid mass takes the profile of the mould, begins to solidify to its surface and leaves the mould during a semi-solid wire.
At an equivalent time, a replacement molten material is supplied to the mould at an equivalent speed to stay up with the solidification wire that leaves the mould; note that the wire is further cooled by a water spraying system. Through intensified cooling it's possible to extend the speed of crystallization and generate within the strand a homogeneous structure with fine grain that provides the semi-finished product good technological properties; the solidified wire is then straightened and move the specified length.
Continuous casting is that the perfect method for the assembly of long semi-finished products and allows the assembly of huge quantities during a short time. Compared to casting in moulds, continuous casting is cheaper in terms of energy consumption and reduces scrap. Since all operations are often automated and controlled, continuous casting offers numerous possibilities to adapt production flexibly and quickly to the changing needs of the market and to mix it with digitisation technologies [10; 16].

1.1.3 Hot Rolling

In metal processing, rolling may be a metal forming process during which the metal material is skilled one or more pairs of rolls to scale back the thickness, to form the thickness uniform and/or to confer a desired mechanical property. The rolling is assessed consistent with the temperature of the rolled metal, if the metal temperature is above its recrystallization temperature, then the method is understood as Hot Rolling.

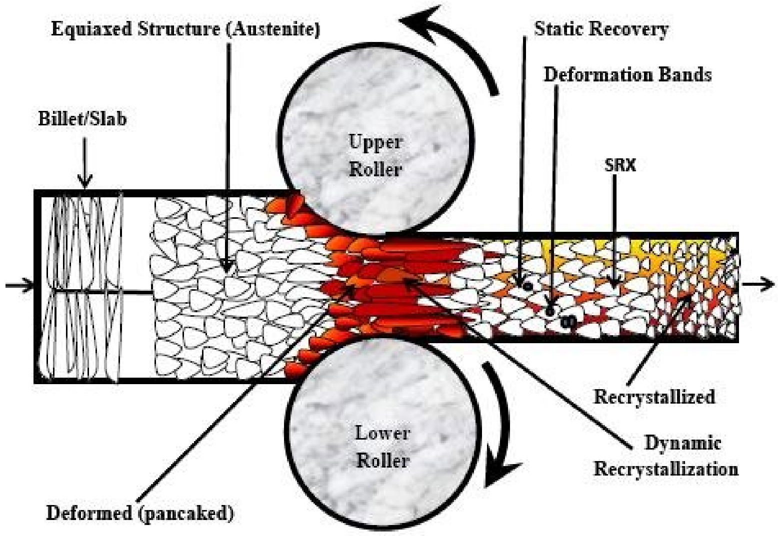


Figure 1.4: Hot Rolling

Hot rolling may be a metal-working process during which the metal is heated above the recrystallization temperature to plastically deform it within the machining or rolling operation. This process is employed to produce shapes with the specified geometric size and material properties, while maintaining an equivalent metal volume; as the material is processed, the temperature must be monitored to make sure that it stays above the recrystallization temperature. To take care of a security factor a finishing temperature is defined above the recrystallization temperature; this is often usually 50 to 100 °C above the recrystallization temperature, if the temperature falls below this temperature, the fabric shall be reheated before further hot rolling [10; 17].
The initial structure of the uneven metal grain consists of huge columnar grains growing within the direction of solidification. This is often usually brittle with weak grain boundaries and should contain defects like shrinking cavities, porosity caused by gas, and foreign material like metal oxides; hot rolling breaks granular structures and destroys boundaries, creating new structures with strong boundaries with uniform granular structures.
At various points during heat treatment, high water is cleaning the steel to get rid

of the mill scale, this prevents the event of superficial imperfections on the ultimate product, eventually, the profiles are cooled. To the present end, the workers check the cooling rate to permit the right microstructure and crystallization of the steel consistent with the intended purpose.
The reduction is high within the first stands and low within the last stand to make sure an honest surface and flatness of the strip. Control of rolling and winding temperatures is important for metallurgical reasons, because it features a considerable influence on the physical properties of hot-rolled strip. Hot rolling improves:
- Toughness and strength
- Ductility
- Resistance to vibration and shock
- Formability
- Surface quality
- Material form (flatness)
- Edge quality

1.1.4 Annealing

With annealing, the material will then pass through a controlled cooling down and deformation (when necessary) in order to achieve the desired mechanical and metallurgical properties.
The material is heated to an intrinsic critical temperature, and maintained at that temperature long enough for the microstructure to essentially restore; the heat introduced by the furnace allows the grains to overcome the consequences of rolling, at which point the metal crystallizes, or precipitate all new equiaxed grains. Small grains grow in size over time, if the grains have grown overlarge, the majority material may have incorrect mechanical properties or an undesirable surface finish.
The first stage is recovery, and leads to softening of the metal through the removal of mainly linear defects called dislocations and internal stresses that cause. The recovery takes place at rock bottom temperature of all annealing processes and before the looks of latest grains without effort; the dimensions of the grain and therefore the shape don't change.
The second stage is recrystallization, where new grains without nuclean strains and grow to exchange those deformed by internal stresses.
In the third phase, if the annealing can continue once the recrystallization is completed, wheat growth occurs, where the microstructure begins roughly and may cause the loss of a considerable a part of its original strength which will however be regained with hardening.
Such a heat treatment requires careful control, even for little variations in temperature, time, or cooling rate which will seriously affect the properties and the sort of warmth treatment depends if it's austenitic, ferritic or martensitic. The surface of stainless steels must be thoroughly cleaned to get rid of carbon residues, grease

and oil before annealing, because the presence of residues leads to carburization which successively, reduces corrosion resistance properties.
Normalization may be a annealing process applied to ferrous alloys to offer the fabric a consistent fine-grained structure and to avoid over-softening in steel. During normalization, the steel is heated to 20-50 °C above its critical temperature for a short period of time and then cooled in air; heating the steel just above its upper juncture creates austenitic grains, which during cooling, form new ferritic grains with an extra refined grain size. Normalization eliminates columnar grains and dendritic segregation to produce a harder and ductile material also improves the workability of a component and provides dimensional stability when subjected to further heat treatment processes [21; 22].

1.1.5 Pickling

After working with high temperatures, mentioned in the previous topics, stainless steel tend to form some surface scales or even a Chromium layer on the surface. The pickling process is used to restore the corrosion resistance of the material by removing these scales and allowing the generation of the Chromia passive layer.
Pickling solutions also remove contaminants like ferrous oxide and ferric particles, and pickling solutions aside from mixtures of nitric and hydrofluoric acids exist and may be used for specialised applications [23].
Different pickling methods could also be used:

- **Pickling within the Batch.**

The composition of the acid mixture and therefore the temperature of the bathtub are chosen consistent with the standard of the chrome steel and the sort of heat oxide.

- **Pickling with pickling paste.**

Pickling paste for stainless steels is an acid mixture with the addition of binders. It's suitable for pickling of limited areas.

- **Pickling with pickling solution.**

The pickling solution normally consists of a mix of aqua fortis and acid, with binding and surfactant agents to get an honest thirophy and therefore the right viscosity; it's suitable for pickling large surfaces.

However, acid cleaning has limits because it is difficult to handle thanks to its corrosivity and isn't applicable to all or any steels. The hydrogen of the acid reacts with the surface and makes it brittle and causes cracks and therefore acid concentrations and solutions temperatures should be kept in check to make sure the specified pickling rates [23].

1.1.6 Cold Rolling

Cold rolling takes place with metal below its recrystallization temperature, usually at room temperature, which increases resistance by hardening. Rather than heat, mechanical stress is employed to vary the structure of metal by also improving surface finish and maintaining tighter tolerances. Cold-rolled products include sheet, strip, bars and rods which are normally smaller than hot-rolled products. Cold rolling cannot reduce the thickness of a bit the maximum amount as hot rolling during a single pass.

The cold rolling process of a metal alloy begins with sheet or coil tape; these materials are placed in large rollers, which compress and crush it under high slightly below its maximum lastingness. Counting on the quantity of compression, different mechanical properties and hardness properties are obtained within the finished product. Through cold reduction, the thickness of the metal are often reduced through the processing of steel strips through a sequence of tandem mill stands where the rollers are stacked vertically and powered by huge motors that exert extreme compression to the metal [18; 20].

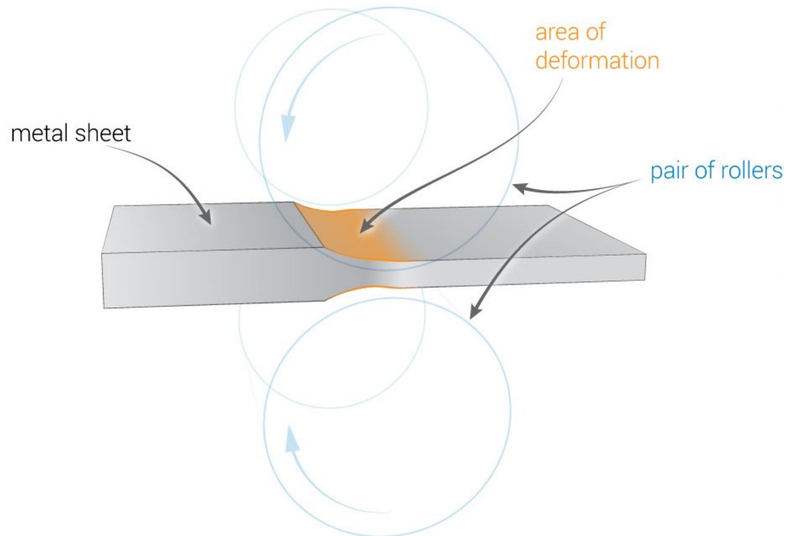


Figure 1.5: Cold Rolling

1.1.7 Finishing Stage

The finishing stage is a very important stage for Stainless Steel production and supply, due to the characteristics that these materials will bring to the applications. One important aspect is the surface quality for aesthetic applications, such as home appliances, elevators and hospital applications; so finishing is a crucial design element and will be specified for those applications where the looks is critical.

The surface finish may have implications for corrosion resistance, wear, friction or maintenance, and thus must be carefully selected and clearly specified.
Properly finished stainless steel is simpler to stay clean for hygienic and commercial applications, like hospitals and restaurants, also in consumer products, the aesthetics of a well-polished chrome steel sheet features a high selling appeal. Additionally to the visual appearance of the gloss, suitably polished chrome steel helps to scale back the danger of bacteria retained by the fabric when utilized in healthcare applications. A surface with a smaller amount of deposits that could become focal points for localized corrosion has better corrosion resistance than a roughly or poorly polished surface, especially when used in aggressive environments.
The main finishing operations for Stainless Steels are: Slitting, surface polishing and other surface treatments (for architectural applications, for example) [19].

1.2 Basic Concepts About Stainless Steels

Stainless steels are base iron alloys containing a significant chromium content (a minimum of 10.5%); in many cases, in addition to chromium, other special chemical elements such as Nickel (Ni), Molybdenum (Mo), Manganese (Mn), Silicon (Si), Titanium (Ti), Nitrogen (N), Aluminium (Al), Cerium (Ce), Niobium (Nb), Copper (Cu) are also deliberately added.
The main characteristic of this family of steels is the corrosion resistance in several environments such as fresh water, seawater, contaminated aqueous solution, acid and basic environments, industrial atmospheres, etc.; a further and important characteristic of this family of steels is the resistance to high temperature oxidation, or chemical corrosion, as typically manifested in hot process gases.
The typical areas of use of stainless steels are related to the automotive, chemical, petrochemical, food industry and paper-making, pharmaceutical, biomedical and transport, off-shore facilities, household appliances, and applications for construction and urban furniture.[1]
The European standard EN-10088 said that: "a steel is considered stainless when it is present in its chemical composition a minimum chromium content of 10.5%". Note, however, that in almost all the chromium content of stainless steels on the market is much higher than the above threshold, reaching, for the most common types, values between 13% and 18%: in practice, in fact, it is necessary a content of at least 12% chromium in order to have a good corrosion resistance in aqueous solutions. [2]
The presence of chromium in alloy guarantees the possibility of forming on the steel surface a very thin film (also called passive film), consisting predominantly of oxides and hydroxides of chromium type Cr_2O_3 and $Cr(OH)_3$: this film is insoluble, compact and well adherent to the substrate and is protective for the material on which it is formed.
The chromium oxide/hydroxide film, being very thin (the thickness is a few nanometers) and transparent to the light radiation, gives stainless steel the typical silver-grey metallic coloration, well visible in the cookware, in the flatware or metal straps of wristwatches; note that any process that changes the thickness of the passive layer can also change the superficial aspect of the Stainless Steels.
All properties described above are the result of the rapid reaction of chromium present in alloy with the oxygen of the atmosphere. The oxidation of stainless steel, also called passivation, manifests itself naturally and spontaneously in neutral oxidant environments, such as in contact with air, or, as is customary in the manufacturing processes of semi-finished products, is artificially induced by immersing the semi-finished product in a dilute solution of nitric acid: the protective oxide film and/or Chromium hydroxide acts in the sense of sealing and placing a barrier between the material and the outer environment.[1]

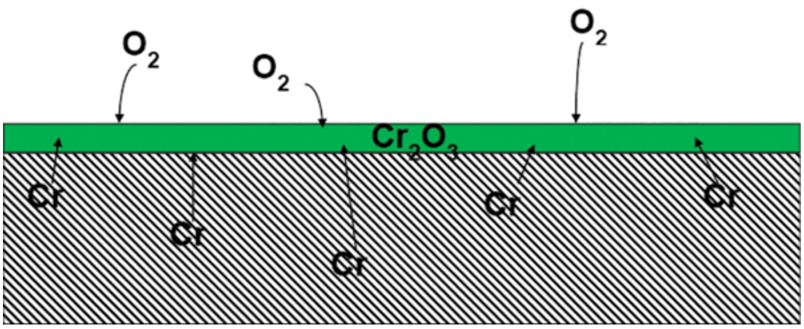


Figure 1.6: Oxide Film Stainless Steel

It’s not completely accurate to say that Stainless Steels are immune to corrosion and oxidation processes, the steel is, indeed, extremely "oxidable" and since it is in the stable state of oxide/hydroxide, it is very "resistant to corrosion and aggression of the surrounding environment".
The passive chromium oxide/hydroxide film also has another important feature: in case it is scratched, abraded or mechanically damaged, will spontaneously reform on the surface of the component, hindering again the corrosive action.

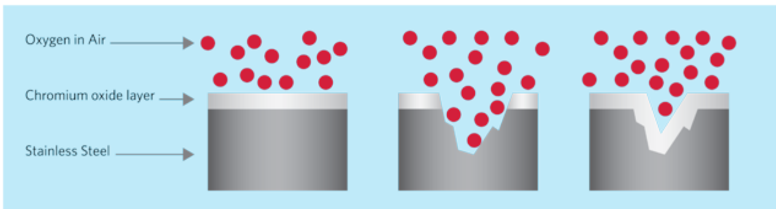
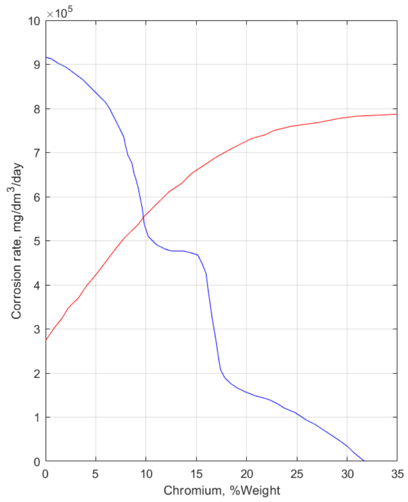


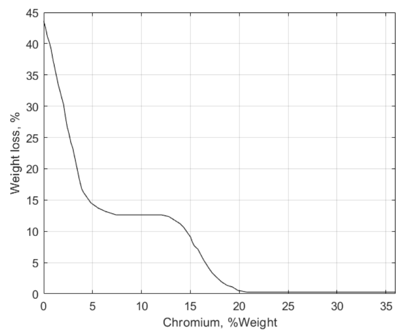
Figure 1.7: Self-Reformed Film Stainless Steel

In addition to generalized corrosion phenomena, the presence of Chromium and the other elements makes it possible to guarantee excellent resistance also to localized degradation mechanisms, such as Pitting and Crevice.
Since, finally, the chromium oxides forming on the surface of stainless steels are very stable at temperatures higher than that environment, the material will also exhibit high oxidation resistance and to hot corrosion.

It is known as in the presence of nitric acid, that is, an oxidizing acid that promotes the passivation of chromium, the corrosion resistance of the steel increases as the chromium content increases, while in the presence of a reducing acid such as sulphuric acid, the rate of corrosion follows an entirely opposite course.
It can then be concluded that the higher the amount of chromium alloyed, the greater shall be the corrosion resistance of stainless steel: this is valid both under wet corrosion conditions and as a result of hot oxidation phenomena.
Strength, durability and corrosion resistance are the most important properties of stainless steels and, in addiction, it is aesthetically pleasing, easy to produce, clean,



(a) Aqueous solutions of nitric acid (blue) and sulphuric acid (red).



(b) Hot oxidation in air.

Figure 1.8: Corrosion rate of iron-chromium alloys in terms of weight

and maintenance, and environmentally friendly, which makes it a top choice for components for architecture, automobiles, and many other products.
However there are several different Stainless Steel Families around the world, in fact "Stainless steel" is actually a term used to refer to iron-based alloys that contain chromium; there are more than 100 grades of stainless steel. These are differentiated by the percentage of chromium, nickel, molybdenum, and other alloy elements, and can be grouped the different grades, depending on the metallurgy and chemical composition into 5 main different Families of Stainless Steels [1; 9]:

- Austenitic.
- Ferritic.
- Martensitic.
- Duplex.
- Precipitation-Hardened (PH).

The most important for this study are austenitic and martensitic stainless steels.

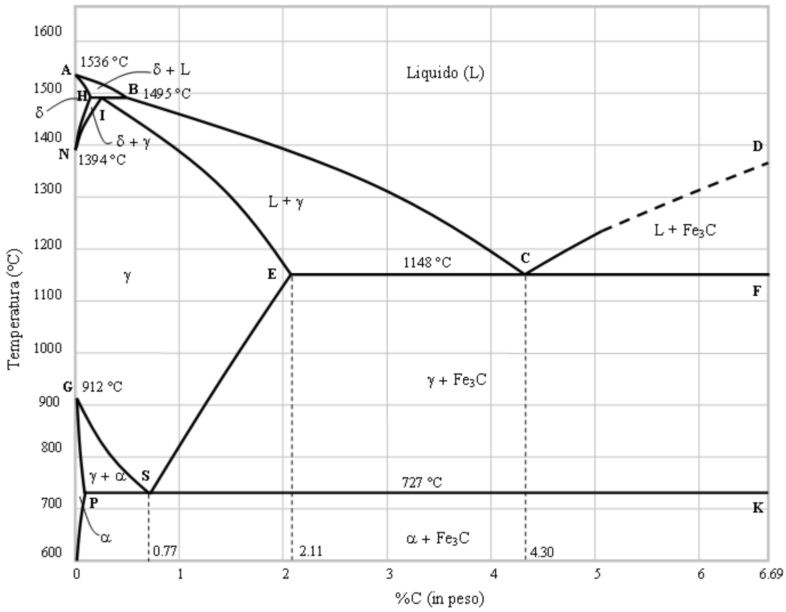


Figure 1.9: Iron-Carbon Phase Diagram

1.2.1 Austenitic Steels

Austenitic stainless steels are defined by their FCC (Face Centered Cubic), and the austenitic structure together with its high ductility entail exceptional toughness characteristics, even at low operating temperatures; good toughness results in poor material shattering.

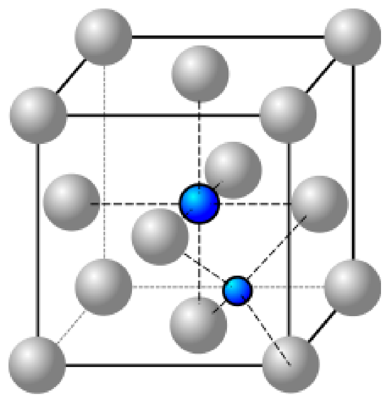


Figure 1.10: Crystalline structure of austenite

When added gammagenic elements (such as Nickel, Carbon and Nitrogen), the steel becomes austenitic: the chemical composition determines the particular grade of stainless steel, whereas the solid solution crystalline structure within the material could be a key feature.

This is the foremost ordinarily used variety of stainless-steel, and with sensible reason, with its exceptional in use properties, such as corrosion resistance and formability, it is widely used in many areas.
There are two sub-groups of austenitic stainless steel: 300 and 200 series; their different nickel levels translate into distinct properties.
The stainless steels of the series 300 are iron-based with a high nickel content, which means that its nickel alloy is at least 8% or more and thanks to this high nickel content has greater corrosion resistance; stainless steels of the 300 series are the largest subgroup.[4]
In contrast, the stainless steels of the 200 series have a lower nickel content and, due to the high price of nickel, series 200 stainless steels are used in many application sectors to reduce production costs. It is partially replaced by other alloy elements that can produce austenitic steels, such as nitrogen, manganese and copper; nitrogen could be a common alloy in 200 series stainless steel. The stainless steels of the 200 series are characterized by a reduced ductility compared to the 300 series, however, the increase in nitrogen levels results in better shock resistance and resistance. [3]

Table 1.1: Average content by weight (%) of the major alloying elements of most common Cr-Ni austenitic stainless steel grades [3]

EN	**EN designation**	**AISI**	**C**	**Cr**	**Mo**	**Ni**	**Others**
1.4310	X10CrNi18-8	301	0.10	17.5	NS	8	NS
1.4301	X5CrNi18-10	304	<0.07	18.5	NS	9	NS
1.4307	X2CrNi18-9	304L	<0.030	18.5	NS	9	NS
1.4305	X8CrNiS18-9	303	<0.10	18	NS	9	0.3
1.4541	X6CrNiTi18-10	321	<0.08	18	NS	10.5	Ti: 5xC $\leq$ 0.70
1.4401	X5CrNiMo17-12-2	316	<0.07	17.5	2.2	11.5	NS
1.4404	X2CrNiMo17-12-2	316L	<0.030	17.5	2.25	11.5	NS
1.4571	X6CrNiMoTi17-12-2	316Ti	< 0.08	17.5	2.25	12	Ti: 5xC $\leq$ 0.70

Heat-resistant stainless steels can be used at high temperatures, usually above 600 °C, they shall be corrosion-resistant and maintain mechanical properties, mostly yielding and slip-resistance. Corrosion resistance is mainly provided by chromium, with addition of silicon and/or aluminum, nickel does not withstand well in sulfur-containing environments and this is usually cured by adding more Si and Al which form very stable oxides; rare earth elements such as cerium increase the stability of the oxide film.

Table 1.2: Typical composition of the major grades [3]

EN	AISI/ASTM	UNS	C	Cr	Ni	Si	Mn	Others
1.4878	321H	S32109	<0.1	18	10.5	-	-	Ti:≤5xC
1.4818	-	S30415	0.06	19	10	-	-	N:0.16; Ce:0.05
1.4828	-	-	<0.2	20	12	2.0	-	-
1.4833	309S	S30908	<0.08	23	13	<0.75	-	-
1.4872	-	-	0.25	25	7	-	9	-
1.4845	310	S31008	<0.1	25	20	-	-	-
1.4841	314	S31400	<0.15	25	20	1.8	-	-
1.4876	Alloy 800	N08800	< 0.12	21	32	-	-	Al:0.4; Ti:0.4
1.4854	Alloy 353MA	S35315	0.06	25	35	-	-	N:0.15; Ce:0.06
1.4886	330	N08330	<0.15	18.5	35	-	-	-

Austenitic stainless steel has many positive characteristics [4]:

- **Strength at Temperature.**

Some austenitic stainless steel can withstand extreme temperatures, counting on the grade up to about 1038 °C; some degrees begin to see a deformation, softening, or loss of force at 427 °C.

- **Cold Workability.**

Heat treatments cannot harden austenitic stainless steels, only cold machining or reduction can increase the strength of austenitics and cold machining refers to modeling a metal without heating it; austenitic stainless steels can be annealed before cooling rapidly or "tempering" the metal to bring it back to its original state. Cold rolled stainless steel has several advantages: a better surface finish is advantageous because a steel with a better surface finish will have a higher hardness that resists the propagation of cracks and a better resistance.
Cold working is usually wont to give chrome steel components the specified final shape and/or to extend their mechanical properties; the method can sometimes cause expected changes within the electrochemical behavior of the fabric.
It is possible to find different trends thanks to cold working:
- Moderate cold work is useful for corrosion resistance, often becoming harmful when the quantity of cold work is excessive.
- Sometimes cold work are often harmful.
- There’s a decrease in corrosion resistance for moderate cold work then a rise for higher cold work.
- For highly interstitial austenitic stainless steels, neither localised corrosion nor general corrosion appear to be seriously suffering from cold rolling.

Deformation affects various metallurgical variables that are often assumed to be ready to change the corrosion resistance of austenitic stainless steels. During the cold machining process, the grains are deformed and needle-shaped structures and bands are formed, these microstructural changes can affect the electrochemical behavior of steel; furthermore, in austenitic stainless steels, deformation-induced martensite may occur, which, when present in large quantities within the material, changes the tensile stresses within the compressive ones. The presence of martensite is assumed to scale back the corrosion resistance of austenitic stainless steels and therefore the formation of martensite from metastable austenite implies a rise in volume. The specific structural changes that occur in chrome steel thanks to cold machining depend upon the composition of the alloy and therefore the conditions of the cold machining procedure.

- **Low Thermal Conductivity.**

The heat transfers slowly through austenitic stainless steel while ferritic stainless steel, on the other hand, has a higher thermal conductivity.

- **Formability.**

Austenitic stainless steel is highly formable, making it particularly versatile for a wide variety of applications.

Of course, different stainless steels have advantages in several applications, as well; austenitic stainless steel is more susceptible to stress corrosion cracks than to ferritics; austenitic stainless steel is not usually magnetic, while ferritic stainless steel is usually magnetic; within the annealed state it is vital to note that austenitic chrome steel is typically characterized as non-magnetic, however cold-rolling steel, or reduce its thickness and increase its hardness, introduces a particular amount of magnetism to the fabric. Austenitic steels can be found in many areas of applications, including:

- Automotive components.
- Mechanical and Power Plant Engineering.
- Power tools.
- Harvesting Machines.
- Valves.
- Cutlery.
- Cookware.

Austenitic stainless steels are used for a lots of products based mainly on their corrosion resistance but also for their resistance, formability and properties at extreme temperatures, also, since their initial cost is usually above that of other materials, their popularity is predicated on their cost minimization over the whole life cycle of their use.
Pharmaceutical, petrochemical, food, pulp and paper, chemical industries are heavily enthusiastic to austenitic stainless steels because their corrosion resistance produces low maintenance, lack of product contamination, high cleanability and long service life. Simple welding and fabrication are important in these applications, but stainless steel is employed just because it's the most cost effective material which will do the work; the initial cost is often a poor measure of a material, as in the case of concrete bars, where the entire structure is compromised by corrosion of a minor component.
Sometimes also formability becomes an important requirement; stretched parts, like sinks, are an example of the utilization of more unstable austenitic grades, while highly stable grades are used for deeply drawn parts or components where low magnetic permeability is sought.
Because austenitics are hard even at liquid helium temperatures they are widely used in all cryogenic applications; only, they are equally useful for uses up to 800 °C, where they are widely used in heat exchangers, boilers, turbines, ovens and automotive exhaust systems, where the formability of ferritic or their resistance to sliding is insufficient.
Like noble metals, stainless steel can also be used simply for its aesthetic appeal; the numerous surface finishes that can be applied to stainless steel, from mirror to matt, do not degrade over time and maintain their appearance as well as their functionality. [5]

1.2.2 Martensitic Steels

Martensite, the hardest structural component of steels; martensitic steel is a type of stainless steel that is known for its high mechanical properties and possibility of increasing wear and strenght of the components; these qualities make martensitic steel a good choice for a variety of applications.
The exceptional hardness of martensite comes from the solid solution of carbon that leads to a crystalline structure centered on the tetragonal body, thus deviating from the cubic structure characteristic of austenite and ferrite. Austenite, which is a prerequisite for martensite formation, is fairly soft in its anneal condition, because of the carbon dissolved in austenite and a subsequent martensite transformation phase can be formed by a hardening procedure in which the carbon is trapped; the resulting crystalline asymmetry is the secret behind the extreme hardness of martensite. [8]

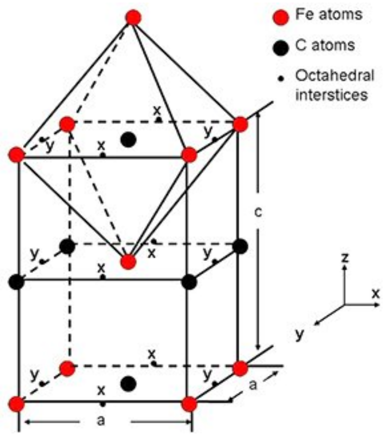


Figure 1.11: Crystalline structure of martensite

Like all stainless steels, the main component of martensitic steel is chromium, which usually represents 11.5-18% of its composition; other common components include up to 1,2% carbon and nickel. The high amount of carbon gives this type of steel a strong molecular structure but the lack of nickel makes it less resistant to corrosion than other types of stainless steel, also, small amounts of other alloy elements such as manganese, molybdenum and nickel are also added.
Lots of processes can be utilized to harden martensitic steel [7]:

- **Age Hardening.**

By heating it to form precipitates that prevent the movement of defects in the molecular structure of the steel, the steel is hardened, metal gets harder and stronger because of these defects; after heating, it's then stored for hours at a heat until is completed, this method usually wont to increase the strength of martensitic steel.

- **Annealing.**

Annealing involves heating the steel to make the molecular structure of the steel more homogeneous and eliminate stresses, this results in softer steel that is easier to handle.

- **Quenching and Tempering.**

Quenching is a process that hardens the steel by heating it, cooling it quickly and heating the metal again; the metal is hard but very brittle after initial heating and cooling, but the second heating is intended to bring the steel back to a temperature to which it is ductile.

Inside the hardening of martensitic stainless steels it's important to possess all the soaking times correct because "reach the utmost solution of chromium-iron carbides for max resistance and corrosion resistance". If the impregnation times aren't correct, we risk the expansion of wheat, the austenite retained, the formation of cracks and fragility, if cooled slowly, carbide precipitates can form round the grain edges of the fabric, which may be a negative effect during this processing so you need to focus on soaking and quenching times.
In conclusion, with the rise of the austenitization temperature, the grain size increases, while the austenitizing temperature increases, the hardness increases and while the trouble that revives the temperature increases, the hardness decreases [26].

Martensitic Steels can be divided into two groups:

- **Low carbon martensitic steel.**

Low carbon martensitic steel has a carbon content of between 0,05% and 0,25%; low carbon versions of martensitic steel are stronger, offer higher corrosion resistance and better manufacturing potential.

- **High carbon martensitic steel.**

High-carbon martensitic steel generally has a carbon content of between 0,61% and 1,50%; a higher carbon content makes steel stronger because carbon strengthens the molecular structure, however, it also makes the metal more brittle and cannot be welded or easily formed into other shapes.

Table 1.3: Chemical composition of a few common martensitic stainless steel grades [6]

EN	**EN designation**	**AISI**	**C**	**Cr**	**Mo**	**Others**
1.4006	X12Cr13	410	0.12	12.5	-	-
1.4021	X20Cr13	420	0.20	13.0	-	-
1.4116	X50CrMoV15	-	0.50	14.5	0.65	V:0.15
1.4104	X14CrMoS17	430F	0.14	16.5	0.40	S:0.25
1.4122	X39CrMo17-1	-	0.40	16.5	1.10	-
1.4125	X105CrMo17	440C	1.10	17.0	0.60	-
1.4057	X17CrNi16-2	431	0.17	16.0	-	Ni:2.00
1.4418	X4CrNiMo16-5-1	-	$\leq$0.06	16.0	1.10	Ni:2.00
1.4542	X5CrNiCuNb16-4	630	$\leq$0.07	16.0	-	Ni,Cu:4.00; Nb:5xC to 0.45

In addition to its strength, martensitic steel has multiple properties that differentiate it from other types of stainless steel [1; 7]:

- **Weldability.**

Martensitic steel is usually brittle and most forms don't react favorably to welding, however, hardened and tempered martensitic steel decreases its fragility and increases its applications. The quenching and tempering process involves heating the metal and then quickly cooling to set in place quickly; high carbon martensitic stainless steels are not generally recommended for welded applications.

- **Magnetism.**

Many types of martensitic steel are magnetic, the crystalline molecular structure can be magnetic if there is iron in the alloy. Magnetism can make metals easier to order, but it can make welding and other manufacturing processes more difficult; martensitic steels are magnetic in both annealed and hardened states.

- **Formability.**

Formability is the ability of a metal to be transformed into different forms without breaking or cracking; the formability of martensitic steel decreases as the carbon content increases.

- **High Strength.**

Martensitic stainless steels are mainly used, but not always, where high mechanical properties are required; their degree of corrosion resistance is more of a limiting think about their application than that of other alloys within the chrome steel family. Often, some surface corrosion spots will appear on their surfaces and, when only limited corrosion resistance or resistance to high temperatures is required, they can be used in the annealing condition, but their highest corrosion resistance is achieved in the hardened or tempered condition.

- **Annealed Martensitic Stainless Steel.**

Martensitic qualities are typically provided to producers in the annealed state because this state provides the best forming characteristics; a hardening heat treatment generally follows the forming operations.

Chapter 2

STAINLESS STEELS FOR ASEPTIC APPLICATIONS

Figure 2.1: Stainless Steel pipes in Clinton Aluminum Industry

Stainless steel isn't degradable and is 100% recyclable, therefore, is recycled to supply more steel and this process continues indefinitely. Stainless steels can have varying amounts of nickel, iron, chromium and molybdenum among other raw materials which are in high demand and thus stainless steel has high catch rates; along side these, there are the foremost usual non-metallic components like carbon and nitrogen that are found in steels which are worth recovering [28].
Stainless steel is actively recycled on an outsized scale round the world by recyclers who collect and process scrap for rewiring it round the world and specialist skills and complicated technologies are needed to separate and prepare each sort of alloy for the recasting by stainless steelworks [46].

Stainless steel scrap falls into two categories:

- **Reclaimed scrap** (also referred to as old scrap)

The reclaimed scrap comes from finished products - like chemical tanks, structural elements or equipment - or from the structural remains of demolition and has often already been used; hence the choice name: old scrap.

- **Industrial scrap** (also called new scrap)

Industrial scrap is that the scrap and excesses of production, manufacture or construction, practically it's formed by scrap pieces from the utilization of stainless steel as a production material. Unlike old scrap isn't used, it's simply not useful in its current form; hence the choice name: new scrap.

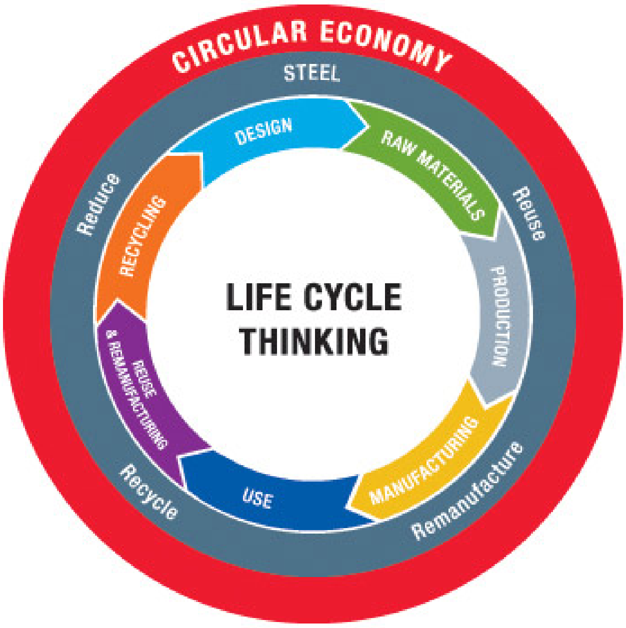


Figure 2.2: Steel recycling cycle

Nowadays, stainless steel consists of about 60% recycled content divided into:
- 25% of recovered scrap
- 35% industrial scrap
- 40% of latest raw materials

The service lifetime of stainless steel products is long, therefore the availability of scrap depends on production levels decades ago [46].
Stainless steel is easy to sterilize and utilized in many applications; actually, commonly all interact daily with stainless steel products, which may be found within the kitchen, on the road, within the medical office or within the buildings. Later will be studied in detail some applications especially, however, generally, it's often used in:

- **Chemical, Processing and Oil and Gas Industries**

The most demanding industries using stainless steels are chemical, processing and oil and gas industries have created an outsized marketplace for stainless steel tanks, pipes, pumps and valves which are utilized in desalination plants, purification plants, offshore oil plants, port supports and naval propellers. Stainless steels are widely used for his corrosion resistance in aqueous, gaseous and heat environments, their mechanical properties in the least temperatures and, occasionally, for other special physical properties. This is the world that suffered most with the COVID-19 crisis, thanks to the reduction of flights, closures and various restrictions imposed by the varied states. Global energy demand declined by 3.8% within the half-moon of 2020, with most of the impact felt in March 2020, when containment measures were applied in Europe, and in most of the planet [47]:

- Global demand for coal has been hit harder, falling by almost 8% compared to the primary quarter of 2019. Three reasons converge to elucidate this decline: China, which may be a coal-based economy, was the country most suffering from COVID-19 within the first quarter; cheap gas and therefore the continued growth of renewables elsewhere challenged coal; mild weather limited the utilization of coal.
- The demand for oil has been strongly affected, with a decline of just about 5% within the half-moon, mainly thanks to the reduction in mobility and aviation, which account for nearly 60% of worldwide demand for oil. At the top of March 2020, global road transport activity was almost 50% below the 2019 average and aviation 60% below.

- **Power Generation**

Stainless steels are widely utilized in the energy production industry to fight corrosion, particularly at high temperatures; for instance, the nuclear industry uses large quantities of Stainless Steel, often specifying a coffee cobalt content, both for energy generation and for radiation containment. Generally, stainless steels are widely utilized in all kinds of power plants, from nuclear to solar, also because they're ideal as mechanical supports for energy generation units when the permeation of gases or liquids is required, as filters in cooling water or hot gas purification or as structural supports within the generation of electrolytic energy.
A crucial attribute of stainless steel is its ability to transfer heat, which is a crucial feature when it involves electrical components, because it allows stainless steel components to be ready to withstand the high temperatures and extreme pressure often present during a power generation plant. Other advantages of stainless steel for energy production include the high strength of the metal to the load ratio, weldability, machinability, durability, wear resistance and skill to face up to extreme temperatures.
With the arrival of green energy options, the range of plants and equipment for power generation has greatly expanded. In modern plants, common applications

that need stainless steel include cooling, heat exchange, combustion, boiler superheaters, heater pipes, and water wall panels. Green energy, and solar power especially, has become a watchword today, because it may be a rapidly expanding industry. A good sort of solar technologies are developed to require advantage of the sun's natural energy as this sector is extremely promising and new innovations still emerge. These technologies use corrosion-resistant stainless steels for staple production and solar power production.
These include solar cells, also called photovoltaic cells, which convert sunlight directly into electricity. The photovoltaic takes its name from the method of conversion of sunshine (photons) into electricity (voltage). Today, thousands of individuals feed their homes and businesses with individual solar photovoltaic systems and repair companies are using photovoltaic technology for giant power plants. The renewable biogenic material may be a source of staple for the assembly of photovoltaic cells. The assembly of amorphous silica used for cells are often quite corrosive and requires the utilization of high-performance, high-recycling, ecological stainless steels and nickel-based alloys in its production.
Concentrated solar power (CSP) is another energy-producing option that creates extensive use of stainless steel. With this method the energy of the sun is captured and concentrated with mirrors to heat fluids that successively heat water to supply steam; steam turbines then generate electricity.
During the crisis from COVID-19 the renewables are the sole source that has recorded a rise of the question, guided from a greater installed ability and therefore the dispatching priority. On the opposite hand, the demand for electricity has been significantly reduced thanks to blocking measures; it's been depressed by 20% or more during times of total blocking in several countries, since the increases in residential demand are far exceeded by reductions in commercial and industrial operations.
Looking at the whole year, we explore a scenario that quantifies the energy impacts of a widespread global recession caused by months of restrictions on mobility and social and economic activity. The results of this scenario is that the demand for energy contracts by 6%, the most important in 70 years in percentage terms and therefore the largest in absolute terms [47].

- **Food Production**

Stainless steels are widely utilized in the assembly and storage of food not such a lot due to the corrosivity of the food itself, but because the utilization of stainless steel allows a faster and more efficient cleaning, plus one among the good advantages of stainless steel is that it doesn't taste the food it comes into contact with [27].

- **Architecture, Building and Construction**

Architecture, building and construction are a growing market as many modern buildings use stainless steels for cladding, roofing and facades; in favor of the utilization of stainless steel there's the low maintenance cost and therefore the Vandal-strength characteristics of steel providing a growing market publicly transport, ticket vending machines and road furniture.
With the move towards sustainable construction, stainless steel, which may be a highly recyclable metal, is becoming increasingly preferable to use in construction and with a refined finish or grain, has aesthetically pleasing properties and may help improve natural lighting within the building like in Arena Castelão (Figure 2.3).

Figure 2.3: Arena Castelão made with AISI 444

- **Medical Applications**

Stainless steel is preferred in clean and sterile environments because it is straightforward to wash and doesn't easily corrode and may be utilized in the development of surgical and dental instruments, operating tables also as other medical equipment like steam sterilizers, cannulas and MRI scanners. Surgical implants like bone reinforcements and replacements are made from special alloys formulated to resist corrosion, mechanical wear and biological reactions in vivo.

- **Automotive**

Stainless steel within the automotive sector is especially used for exhaust systems and catalysts, but also for structural purposes. The utilization of stainless steel is increasing with greater specialise in low long-term maintenance costs, lower environmental impact and increased concern about life-cycle costs, making the stainless steel market still improve.

It is important to specify that stainless steels are widely utilized in hospitals, food industries and kitchen appliances due to their superior corrosion resistance, ductility and machinability; however, they are doing not possess antibacterial properties and it's been known that an outsized a part of the acquired hospital infections are derived from contact transmission.
There are an outsized number of applications of stainless steels during which they are available into contact with human skin and this contact are often a transient skin contact, as often happens with handrails or in daily handling, for instance, cutlery and kitchen equipment. As demonstrated by decades of daily experience, this sort of contact is safe for human health.
However, nickel allergy are often found in some individuals thanks to direct and prolonged contact of metal articles with human skin, which may end in metal release through contact with human sweat. This may cause the discharge of bioavailable divalent nickel ions that migrate to human skin and should cause an allergy in individuals already sensitized to nickel.
The amount of nickel ions sufficient to induce sensitivity varies consistent with the individual and among the determinants of susceptibility and therefore the rate of nickel sensitization are the temperature, the presence of other allergic conditions, race, sex and age.

2.1 Medical Industry

Figure 2.4: Stainless Steel for Medical Equipment

When it involves the medical industry, equipment that has corrosion is dangerous for patients and a little infection can create very serious medical problems, so stainless steel solves this problem alright. Stainless steel is found in:
- Hospital beds
- Wheelchairs
- Walkers
- Surgical equipment like scalpels
- Precision stainless steel tubing
- Orthopedic implants
- Artificial heart valves
- Bone fixation
- Mandrels / Tools
- Chemical / Hazardous waste containers
- Wires
- Curettes
- Screws / Prostheses / Plates
- Medical needles
- Medical syringes
- Sensor probes
- Catheters
- Otolaryngology ear scope nozzles
- Sinks / Knives / Surfaces / Bowls / Trays

Stainless steels play a crucial role within the medical sector, that varies from surgical operations to biomedical implants and therefore the criticality of such application requires that these steels are highly safe within the physical body which they're also highly immune to a high level of strict acids involved in cleaning and sterilization. These surgical stainless steels are made from important elements like chromium, copper, nickel and molybdenum which contribute significantly to the over-all properties of steel. The added elements gave the power for surgical steels to present the following:
• Copper: improves resistance to atmospheric corrosion.
• Chrome: increases the resistance to scratches and corrosion of materials and is therefore perfect for cleaning and sterilization.
• Nickel: provides a particularly smooth and polished surface
• Molybdenum: provides hardness after forming and is right for sharp cutting edges
In general you have the subsequent properties:
- High resistance to corrosion
- Antibacterial properties
- Non-magnetism
- High resistance to heat
- Recyclability
In some rare cases the body's system has been known to possess an adverse reaction, both cutaneous and systematic, to the nickel content in some stainless steels and in cases like this, titanium are often used as a substitute for stainless steel, however, with titanium comes a costlier solution.
Subsequent medical device guidance has, however, provided further clarification by the introduction of following three definitions supported the duration that the medical device is in touch with human tissue:
- Transient (for fewer than 60 minutes)
- Short term (less than 30 days)
- Long term (more than 30 days)
Martensitic stainless steels utilized in medical devices usually contain up to 1% nickel to enhance their metallurgical properties and ISO 5832-1 and 5832-9 specify, respectively, processed stainless steels and high nitrogen stainless steels for surgical implants.
Devices designed for medical use must meet extremely strict design and manufacturing criteria as during a world increasingly focused on lawsuits and compensation for injuries or damage caused by medical negligence anything that comes into contact with or is surgically implanted within the physical body must function exactly as designed, without failing.
The top layer or coating of the equipment are susceptible to scratches or wear that leave the steel under very vulnerable and to avoid such concerns, stainless steel uses a passivation effect that causes auto-metal healing when damaged.

Polished surfaces offer greater corrosion resistance and, within the case of an electrogloss finish, a chemically clean surface with better surface roughness. Additionally, the plants are subject to strict cleaning regimes aimed toward removing microbiological contamination, which again promotes corrosion resistance, and are used under sterile conditions.

Bacterial adhesion and biofilm formation on the surfaces of materials can cause serious problems as they often cause microbial contamination. The influence of surface topographies attracted much attention as micro/nano scale structures showed anti-adhesive properties or killing of microbes by direct contact. The initial attachment of the bacteria to the rough surfaces is favored by the irregularities of the surface, where the bacteria are "protected", and may stick with several points of the substrate [24; 25].

Among the factors that influence the attack of bacteria on a surface are the properties of the bacterial surface, the presence of organic molecules and therefore the properties of the available surface. The knowledge of the effect of surface properties on the adhesion of bacterial cells is of great interest because the control of bacterial colonization and its effective removal are of fundamental importance. Bacterial attachment and various cleaning experiments using stainless steels of varied roughnesses have shown that smooth steel surfaces haven't any advantages over coarser steel surfaces in terms of resistance to bacterial attachment or removal of bacteria. In general, researchers have found that adhesion forces increase with increased surface roughness and increased adhesion of cells to coarser surfaces; others argued that a rise in surface roughness didn't affect or maybe inhibit the adhesion of bacteria.

Stainless steel surfaces have greater hygiene value and need lower concentrations of disinfectant to realize the extent of hygiene required. This is often particularly important in healthcare environments which are crammed with chemical compounds like iodine, bleach, peroxide, dyes, human tissue, blood and bodily fluids which will play havoc on solid surface sinks, countertops, tables, bathroom fixtures, also as fabric covered chairs.

Now it is possible to provide a contemporary coating made with micelles and applied during the assembly of stainless steel that gives stainless steel excellent resistance to bacteria and allows the fabric to sanitize. This innovation is certain to seek out applications across a whole spectrum of medical tools and devices within the near future.

Overall, thanks to reduced repair and maintenance costs, long-term savings are often within the range of 30 to 40 % compared to alternative materials. Discerning engineers, specifiers and designers weigh the long-term value of stainless products against the doubtless higher initial costs and conclude that, over the entire lifetime of a project, stainless is usually the simplest value option [24; 25].

- **Stainless Steel 304**

Stainless Steel 304 is taken into account worldwide together of the foremost suitable materials for the manufacture of medical devices for all kinds of applications as no other sort of stainless steel is out there in numerous forms, finishes and with such different applications. Stainless steel 304 offers features and properties that thus making the logical choice for medical device specifications.
Stainless steel 304 advantages are:
- Are often used for all kinds of medical devices while reducing staple costs.
- High resistance to corrosion.
- Recyclable.
- Antibacterial properties.
- Are often cleaned and reused repeatedly within the medical field.
- Isn't magnetic.
- High resistance to heat.
- Once hardened it retains its shape.

- **Stainless Steel 316L**

316L stainless steel is right for the development of medical and surgical instruments, which require high levels of reliable performance; this steel is renowned for its high mechanical properties and its first-class corrosion resistance. Its metallurgical composition makes it an allergy steel and therefore the 'L' refers to its low carbon content, which makes it very corrosion resistant.
AISI 316L is austenitic stainless steel; it's not magnetic and thus doesn't interfere with the sensitive instrumentation; it offers excellent formability and, despite its excellent properties for medical production, isn't the foremost expensive stainless steel, but is significantly costlier than other grades like the 304. Stainless steel 316L advantages are:
- Excellent corrosion resistance.
- Excellent resistance to heat.
- Is not generally weldable using oxyacetylene welding methods.
- Easy to figure but tends to harden if worked too quickly.
- These grades can't be hardened by thermal treatment.
- It are often hot worked using the foremost common hot working techniques.
- It doesn't harden in response to heat treatments, but it are often hardened by cold processing, which may also cause a rise in strength.

- **Stainless Steel 317L**

AISI 317L stainless steel is an austenitic stainless steel containing 3% molybdenum with a superb resistance; its main feature is that the welcome addition of molybdenum to its chemical composition, which provides greater resistance to chemical attacks than austenitic chromium-nico-molybdenum steels of the AISI 316L type and improves pitting resistance from chloride ion solutions. This grade has about 1% more chromium, nickel and molybdenum than austenitic AISI 316L steel.
The 317L alloy is an additional low-carbon version of the austenitic alloy type 317 chrome-nickel, isn't annealed magnetic and can't be hardened by heat treatment, but hardens by cold machining. It's excellent corrosion resistance during a wide selection of chemicals that's usually an equivalent as 317 alloy in any environment; the only exception is when the alloy is exposed to temperatures within the precipitation range of chromium carbide (427 – 816 °C) where, thanks to its low carbon content, the 317L provides intergranular attack resistance.

2.2 Food Industry

Figure 2.5: Stainless Steel cookware

The frequent gastrointestinal disorder and food-borne diseases that have occurred in recent years have led people to pay great attention to food safety, especially food contact materials which are essential in food chains and in lifestyle, and ensuring their clean hygiene is of great importance so as to prevent micro-viral contamination and therefore the spread of food-borne pathogens.
The most common source of contamination comes from the varied stages of the food production chain, like processing, storage, transportation, cooking, selling, which are extremely susceptible to cause microbial invasions. Within the food supply chain, if hygiene control measures aren't applied, conditions are going to be created for the expansion of degradation bacteria and, combined with the complexity of the environment, various food-borne pathogens are easily attachable to materials in touch with food, causing secondary contamination of food.
Therefore, maintaining good sanitation of the food environment and get in touch with materials is a crucial think about controlling the danger of microbial contamination of food. Stainless steel is one among the foremost accepted and widely used materials for contact with food [27].
Stainless steel was the primary choice of contact materials thanks to its excellent mechanical properties, workability, corrosion resistance, simple cleaning and aesthetics. It are often seen with the eye that it's utilized in every field of application, from everyday kitchen utensils to central kitchens within the catering industry and even to varied food processing equipment, stainless steel has become a food contact material that's widespread worldwide.

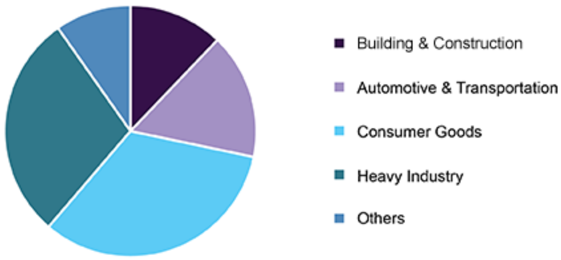


Figure 2.6: Global stainless steel market

More than 30% of all the stainless steel produced is employed within the food industry and that we can find it in:
• Agricultural applications: electrical and mechanical equipment, fences, gates, watering, storage tanks.
• Food processing: predicament lines, bulk storage, transport, preparation.
• Food preparation: cutlery, surfaces, pots and pans, sinks.
• Presentation: exhibitors, stalls.
• Self service machines: food vending machines.
Basically, at every stage of what it takes to bring food to the overall population, there's reliance on stainless Steel. Stainless steel is usually utilized in the food industry because it has the subsequent advantages:
- Waterproof surface prevents contamination.
- Available during a wide selection of versatile finishes.
- Its smooth surface is definitely cleaned.
- It's extremely strong, it doesn't affect, bruise, or easily breaks.
- Not vulnerable to acidic erosion.
- Its surface provides chemical and bacteriological neutrality.
- It's made to blend easily with other finishes.
- It is fire resistant.
- Doesn't take or transfer food smells.
- It's especially immune to corrosion and rusting compared to other metals.
- Low maintenance costs.
The selection of the right stainless steel consistent with operation is significant for safe production and price efficiency and this relies on the appliance. The bulk of stainless steels normally utilized in the food industry are [29]:

- **AISI 304**

304 stainless steel are often a far better choice if:
- The appliance requires a singular formability because it has good forming and welding properties.
- The appliance involves cost problems because it is more convenient.

- **AISI 316**

This features a high resistance to corrosion during a saline environment, features a temperature range of use much above what's required by food preparation. This sort of steel is especially suitable for contact with food, because it features a high resistance to acids, bases and chlorides, like salt.
316 stainless steel are often a far better choice if:
- The appliance includes highly corrosive elements.
- The fabric are going to be placed under water or exposed to water during a consistent manner.
- Application requires higher strength and hardness.

Food business operators have very strict requirements to suits so as to avoid contamination of products and therefore the machines and utensils utilized in catering and restaurants must suits strict hygiene standards, therefore stainless steel is nearly always the sole choice in these areas. The European Framework Regulation has established certain rules and guidelines regarding the utilization of stainless steel products for food production, so if the precise sort of stainless steel is understood and is employed accordingly, then there shouldn't be any quite problem in its use.
In June 2020, the United Nations warned that the planet was facing the worst food crisis in half a century thanks to the recession caused by the pandemic.
The COVID-19 pandemic affects the worldwide food industry while governments close restaurants and bars to slow the spread of the virus, causing that worldwide, the daily traffic of the restaurants has dropped precipitously compared to an equivalent period of the previous year. Restaurant closures have caused a sequence effect among related industries, like food production, liquor, wine and beer, food and drink shipping, fishing and agriculture.
On the other hand, the consumer goods industry in the food sector grew a lot during the COVID crisis, as due to restrictions "closed" people in their homes have invested time and money for new equipment, such as household appliances (dishwasher, etc...) and also cooking wear (cutlery, etc...).
Several prevention methods are adopted, including encouraging contactless payment options and minimising the handling of money and credit cards, putting cash on the counter instead of passing it directly by hand, and frequently disinfect surfaces that are frequently touched, like workstations, cash registers, payment terminals, door handles, tables and worktops, provide remote purchase alternatives, and limit the utmost capacity of consumers at the door.
All types of food are often potentially contaminated through contact with any equipment, surface or contaminated environment, for this reason, proper cleaning and therefore the prevention of cross-contamination are essential for controlling food-borne diseases. Once pathogens are deposited on surfaces from a previously contaminated product (cross-contamination), aerosol, or touch of contaminated

hands or clothing, they will survive on inanimate objects like knives, saws, shipping containers and conveyor belts made from metal, plastic and wood.
Food safety remains the most concern of all producers and normal food handling procedures should be sufficient to combat COVID-19, as long as social distances and other measures are followed. Maintaining social distance within food establishments is difficult because workers stand side by side during long shifts on production lines; additionally, speaking aloud or shouting, thanks to noisy environments, causes more droplets to be released into the air, allowing the virus to spread further. Like any activity during this era, it's essential to stay the staff healthy; this suggests monitoring habits and ensuring hygiene protocols are followed as an infected employee could spread the virus to all or any employees within fortnight, forcing the corporate to shut.

2.3 Water Treatment Industry

Figure 2.7: Water and Wastewater Treatment in Stainless Steel

Stainless steels are used for the treatment, storage and distribution of water for several years and such use is increasing worldwide because it has benefits for society and industry, such as:

- Better water quality.
- Reduced environmental impact at lower cost.

The excellent corrosion resistance of stainless steels when applied correctly is at the idea of those advantages. What is required from a cloth to be used in equipment within the water industry is:
- Maintenance of water purity.
- Approval for use.
- Durability and low maintenance.
- Simple use.
- Cost effectiveness.
- Proven performance.

The most important think about making beverage drinkable is that the removal of bacteria and parasites; water must therefore be kept clean and safe during storage and distribution, which requires high integrity systems and resistance to residual disinfectants. Stainless steels are suitable for meeting these requirements due to their corrosion resistance in both treatment plants and distribution networks.
The most important aspect of design is to attenuate the opportunities for interstitial corrosion in joints by the utilization of welded connections. The importance of

weldability and high stress environment is crucial for this application. If the welds aren't made with quality, you'll have corrosion and bacteria, putting in danger the water treatment. Equipment design also extends to making sure that treatment chemicals are injected and mixed correctly, as they will be aggressive to stainless steels in concentrated form [30].
Attention shall be paid to the assembly of full penetration welds and to the elimination of the oxide film, called heat dye, and therefore the thin depleted layer of chromium slightly below the warmth tint that happens in areas adjacent to the welds when welding is performed. It's an action that must be performed if you would like to urge the simplest corrosion performance because if you don't remove it, these areas of the tube corrode very easily.
Full recyclability of materials at end of life is a crucial consideration for an industry which is as aware of its environmental impact because the water industry. The strength of stainless steels means thin walled pipe designs are possible, even where yield strength is that the limiting factor [30].
Advantages of stainless steel include:

- High strength.
- Uniformity.
- Elasticity under high stress.
- Ductility.
- Adaptations for connections and manufacture.
- Fatigue strength and toughness.
- Resistance to heat deformation.
- No ultraviolet degradation.

Disadvantages of steel use include:

- Maintenance costs thanks to susceptibility to corrosion by air, water and microbiological elements
- Fatigue if subjected to stress reversals (pressure on, then off).

The hygienic nature of a cloth are often defined as a mixture of variety of aspects:
- Corrosion resistance, as shown by inertia with reference to the substances with which the fabric is in touch, so on avoid the disposal of its constituent elements which alter the organoleptic or toxicological properties, and resistance to the action of detergents, solvents, sanitizers and disinfectants, so on allow actions to get rid of even the littlest traces of deposits, dirt and bacterial pollution.
- Absence of any protective coating which, when chipped, wear, crack or otherwise deteriorate, creates superficial discontinuities which become germ receptacles and dirt.
- Compact porous-free Surface.
- High resistance to shock and mechanical stress.
- Resistance to thermal shocks.
- High bacterial removability.
- Low bacterial retention.

Water is one among the foremost prevalent substances on the earth, yet it's the bane of designers and engineers everywhere due to the corrosive impact it's on metal. Fortunately, stainless steel has been ready to largely prevail over the negative effects of water with the event of some extremely durable and anti-corrosive alloys which will perform even within the toughest of environments.
Corrosion is that the deterioration of a metal or alloy because the results of exposure to and reaction with its environment. It's an electrochemical process, sort of a battery, with an anode and a cathode reaction, and ions migrating through an external circuit, even in single metal steel. Positive electrolytes migrate through the liquid electrolyte toward the cathode, whereas negative ions are interested in the anode. The corrosion reaction and the cathode-ray reaction go hand in hand. The typical reactions are [31]:

- $Fe \rightarrow Fe^{2+} + 2e^-$
- $2H^+ + 2e^- \rightarrow H_2$
- $2H^+ + 1/2O_2 + 2e^- \rightarrow H_2O$
- $H_2O + 1/2O_2 + 2e^- \rightarrow 2OH^-$

The first equation is anodic and therefore the rest are cathodic. Corrosion of stainless steels depends almost entirely on chlorides, sulfates and dissolved oxygen content. There are several corrosion types that are common to varied grades of stainless steel:

- Crevice corrosion.
- Chloride pitting.
- Pinhole leaks.
- External corrosion within the sort of corrosion stains often is found in multiple locations on the outside of the pipe.
- Stagnant water always presents a risk for the occurrence of corrosion and microbiological activity.
- Heat tints near welded areas are shown to form the welds vulnerable to biocorrosion.

It shouldn't be a surprise to anyone within the water industry that organisms which will cause microbiologically induced corrosion are present in raw water supplies, no matter the source. This enables the microorganisms to colonize inaccessible areas like the inside of crevices and pits where they will avoid the shear of fluid velocity. The tiny size also facilitates the rapid and straightforward dispersion of microbial cells.
The corrosion resistance of stainless steels not only ensures a long life over time without the need for replacement, but also reduces operating costs due to the low maintenance requirement. However, the advantages don't stop there because when the installation is not any longer needed stainless steels still have residual value then are likely to be fully recycled. Since there's no general corrosion, there are not any corrosion products to deposit on internal surfaces which might reduce both the bore and smoothness of the pipe [31].

Chapter 3

ANTIMICROBIAL STAINLESS STEELS

The whole world is particularly concerned about medical communities quite ever about the disinfection of equipment; the COVID-19 is changing the way we clean, not only in medical facilities but also reception and in our communities. Since stainless steel is one among the foremost preferred materials of the medical profession, it's imperative to know the way to properly sanitize stainless steel equipment. According to a study by the National Institute of Health, the virus causing COVID-19 was detectable for up to 3 days on stainless steel products; therefore, verifying that the right product is employed to disinfect surfaces is critical.
The first step to sterilizing something is to wash it. There's a difference between clean and sterile, something clean has no residue or external materials, while something sterile ensures that there are not any bacteria, mold or other contamination. The most commonly used process is that of autoclaves, as being an efficient and convenient method of sterilization, it's become a fundamental practice. Autoclaves are wont to sterilize at very high temperatures and steam, and steam sterilization is one among the foremost effective, safe and cheap sterilization methods used on most medical devices, the only time they're not considered as a way of sterilization is when the thing to be sterilized is heat-sensitive or can't be steam-sterilized.
The object is sealed in an autoclave bag, which is meant to take care of the integrity of the seal, while allowing disinfection, then placed on a tray or rack for autoclave, an intense amount of pressure and warmth is then applied to destroy any micro-organism. For the procedure to be effective, specific temperatures must be reached and maintained for a particular period of your time [32]. Temperatures and deadlines may vary counting on what's sterilized and which method of sterilization is performed. The foremost commonly used sterilization methods are:
- Gravity displacement steriliser
- High speed prepaid sterilizer
- Steam-push-button washing process

When steam cannot penetrate an instrument or can destroy it, there are other methods of sterilization:

- **Dry heat sterilization**

When steam cannot penetrate an instrument or can destroy it, dry heat is employed. Dry heat may be a strong but slow technique that needs high temperatures and time, for this reason, it's not suitable for several materials, but often it's even more reliable than various other options. Dry-heat sterilization uses air at about 170 °C to kill microbial life.

- **Chemical sterilization**

Chemical solutions like Ozone (O_3), Ethylene Oxide (C_2H_4O), Peroxide (H_2O_2), Bleach ($NaClO$) are involved during this process as these chemicals have the facility to kill a good range of pathogens and have properties that would be harmful to humans. The thing is totally immersed within the chemical prepared for a particular period of your time until the death of pathogens; once sterilized, the thing is rinsed and dried. Chemical sterilization isn't suitable for biological materials, fibre optics and other highly heat-sensitive materials.

- **Plasma gas sterilizers**

This type of sterilization uses coldness plasma gas supported vaporized peroxide inside a chamber to kill any microorganism, including spores, bacteria, fungi and viruses. Once the steam is faraway from the chamber, a plasma of a lower temperature is produced, which ensures total sterilization of all the equipment. Oxygen and water are the remainder of this process and make these sterilizers safe for both the environment and therefore the personnel involved. This is often a costlier method, it's extremely effective and a superb option especially within the case of medical equipment or tools that are sensitive to moisture.

- **Vaporised peroxide sterilisers (VHP)**

VHP sterilizers also use peroxide vapor, but unlike plasma sterilizers they don't use plasma gas within the sterilization process as VHP sterilization removes moisture from the within of a fence, and a generator quickly injects VHP to succeed in a perfect concentration for sterilization of kit. The microorganisms that would be present are effectively faraway from the vapors, sterilizing the envelope; the method is then reversed by the generator, which breaks down the steam into ecological elements.

In addition to sterilization methods, more and more often, the manufacturers address single-use aseptic treatment systems to satisfy or beat the aggressive time of introduction, while controlling costs.
New innovative disposable technologies still be introduced. The advantages of converting to presterilized single-use systems are documented in many papers and case studies, but many of those benefits would be lost if manufacturers couldn't safely connect systems and components to make an entire aseptic process.
Among the various common strategies to improve the antimicrobial properties of stainless steels we will see how scientists have struggled to enhance the effectiveness of bacterial activity of biomaterials by modifying surface chemistry through various agents antimicrobials embedded in organic or inorganic coatings. These approaches have led to improvements, but at an equivalent time they're complex and have variety of great limitations.
Recent studies have shown a shift towards biomimetic/nanostructured surfaces, on which necrobiosis is caused mainly by rupture of the microbial membrane through cell adhesion. Additionally, recently published studies state that nanostructuring plays a key role in improving antimicrobial resistance, since when the bacterial membrane is subjected to mechanical stress, it results in the stretching of the membrane, to rupture and eventually to necrobiosis [36].

3.1 Cu alloying strategies

Despite campaigns for hand washing and routine cleaning, infection rates remain high today and this has raised the necessity to combat pathogenic microorganisms to lower the danger of contracting infections. A promising and effective strategy to stop the spread of micro-organisms in areas sensitive to hygiene is that the improvement of inanimate surfaces with antimicrobial properties. Among the various strategies, metals that kill by contact like copper (Cu) and silver (Ag) gain interest as self-sanitizing material. To the advantage of antimicrobial metals there's the power to significantly inhibit the metabolism of bacteria already only through small concentrations, and thus achieve high antimicrobial effectiveness. Since copper-containing proteins are involved in cell metabolism and thus low-concentration copper is an important chemical element in living organisms, the danger to consumers is minimal.
Copper ions, alone or in copper complexes, are used for hundreds of years to disinfect liquids, solids and human tissues. Today copper is applied as a water purifier, algahicide, fungicide, nematocida, mollusc acid and as an antibacterial and anti-fouling agent, also showing a strong antiviral activity.
For many years, copper has been seen as an undesirable element in production, it's been related to the "hot shortness", where it's fused to the temperatures used for forging and rolling, causing the breaking of the workpieces during machining.
Copper has been more widely utilized in stainless steel castings, because it has been related to enhance the casting performance, however, the positive impact on corrosion resistance in selected environments is far clearer. The corrosion resistance of stainless steels is due to the highly stable passive film forming on their surface when exposed to an oxygen-containing environment. The addition of copper with its subsequent dissolution on the surface results in the precipitation of an insoluble compound of copper sulfide (Cu_2S); this, in turn, prevents the sulfur species from adsorbing on the steel surface, providing during a sense, provides a self-healing effect for stainless steels, which doesn't prevent the onset of pitting corrosion within the weak points of the passive layer, but slows or stops further corrosion at these sites, preventing more damaging corrosion [33].
One of the foremost important issues regarding the utilization of copper is that the reaction between copper and other materials, as they're liable for corrosion, stains and even the "green patina" that develops over time on the surfaces.
When dissimilar metals are in contact with one another within the presence of an electrolyte, the galvanic action occurs, leading to deterioration of the metal with rock bottom galvanic number. The electrolyte could also be rainwater that flows from one surface to a different , or the humidity of the air that contains enough acid to form it act as an electrolyte. Since copper has one among the very best galvanic numbers or nobility of active metals, it'll not be damaged by contact with any of them, however, it'll cause corrosion of other metals if in direct contact.

The oxidation process that provides copper its characteristic green patina is that the results of exposure to an acidic atmosphere, which means that it can have a faster effect in some areas than in others due to higher concentrations of pollutants. When the acid moisture comes into contact with exposed copper surfaces, reacts with copper to make copper sulphate, the acid is neutralized during the reaction with the copper this patina eventually covers the surface and adheres closely thereto, thus providing a protective layer against additional atmospheric agents.
It should be noted that the green patina occurs only in copper-based alloys not on stainless steels containing copper, which retain their original color, so the addition of copper does not affect the aesthetic properties of the steel itself.

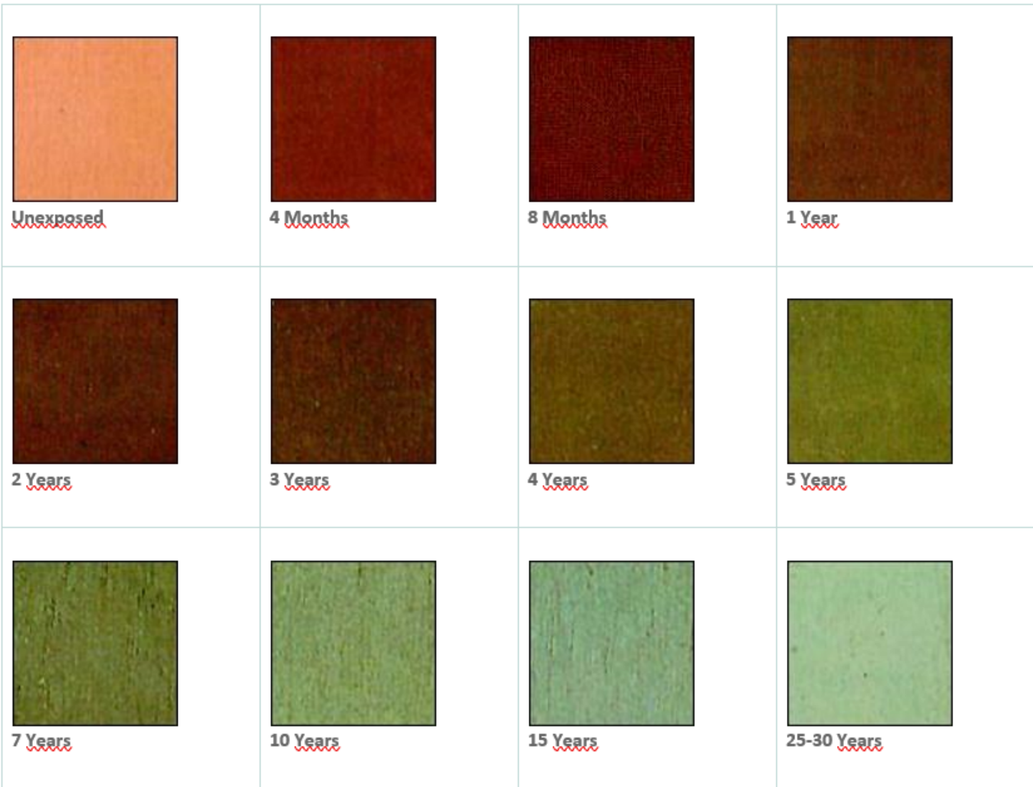


Figure 3.1: Copper oxidation time

Stainless steel with Cu should have a far better uniform corrosion resistance within the air as Cu is one among the alloy elements wont to improve the power of uniform corrosion resistance. One reason why the uniform corrosion resistance of steels are often improved by the addition of Cu is that it plays the role of activation of the cathode, which could promote passivation on the anode and thus reduce corrosion ongoing [33].

Cu^{2+} ions are released through chemical reactions during the pitting corrosion process, and therefore the reactions that occur are:

$$8Cu + 2H_20 + 0_2 \rightarrow 4Cu_20 + 4H^+ + 4e^-$$
$$Cu_20 + 2H^+ \rightarrow 2Cu^{2+} + H_20 + 2e^-$$

Secondly, when stainless steel containing Cu is exposed to a corrosive environment containing Cl^-, the subsequent reactions occur:

$$Cu \rightarrow Cu^+ + e^-$$
$$Cu^+ + Cl^- \rightarrow CuCl$$
$$2CuCl + 2OH^- \rightarrow Cu_2O + H_2O + 2Cl + 2e^-$$
$$Cu_2O + H_2O + O_2 \rightarrow 2CuO + H_2O_2$$
$$2CuO + 2H^+ + H_2O_2 \rightarrow 2Cu^{2+} + 2H_2O + O_2 + 2e^-$$

Third, the Fe/Cu voltaic cell formed on steel could also promote the discharge of Cu ions from its surface and since the electrode potential of Cu (0-34 V) is above that of the stainless steel matrix (0.2 V), the steel matrix tends to be oxidized first as an anode, and therefore the following reactions will occur:

$$Fe \rightarrow Fe^{2+} + 2e^-$$
$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$$
$$Fe(OH)_2 + Cl^- \rightarrow FeClOH + OH^-$$
$$FeClOH + H^+ \rightarrow Fe^{2+} + Cl^- + H_2O$$
$$4Fe^{2+} + O_2 + 12OH^- \rightarrow 4Fe(OH)_3 + 2O^{2-}$$
$$Fe(OH)_3 + 2Cl^- \rightarrow FeCl_2OH + 2OH^-$$
$$FeCl_2OH + H^+ \rightarrow Fe^{3+} + 2Cl^- + H_2O$$

Among the above reactions, Fe^{3+} is generated, and therefore the electrode potential of $Fe^{3+} + e^- \rightarrow Fe^{2+}$ (0.771 V) is above $Cu^{2+} + 2e^- \rightarrow Cu$ (0-337 V) and $CuCl^{2-} + e^- \rightarrow Cu + 2Cl^-$ (0.208 V). Therefore, Cu are going to be first oxidised as an anode at this point, and therefore the following reactions will still occur:

$$Cu + 2Fe^{3+} \rightarrow Cu^{2+} + 2Fe^{2+}$$
$$Cu + Fe^{3+} \rightarrow Cu^+ + Fe^{2+}$$

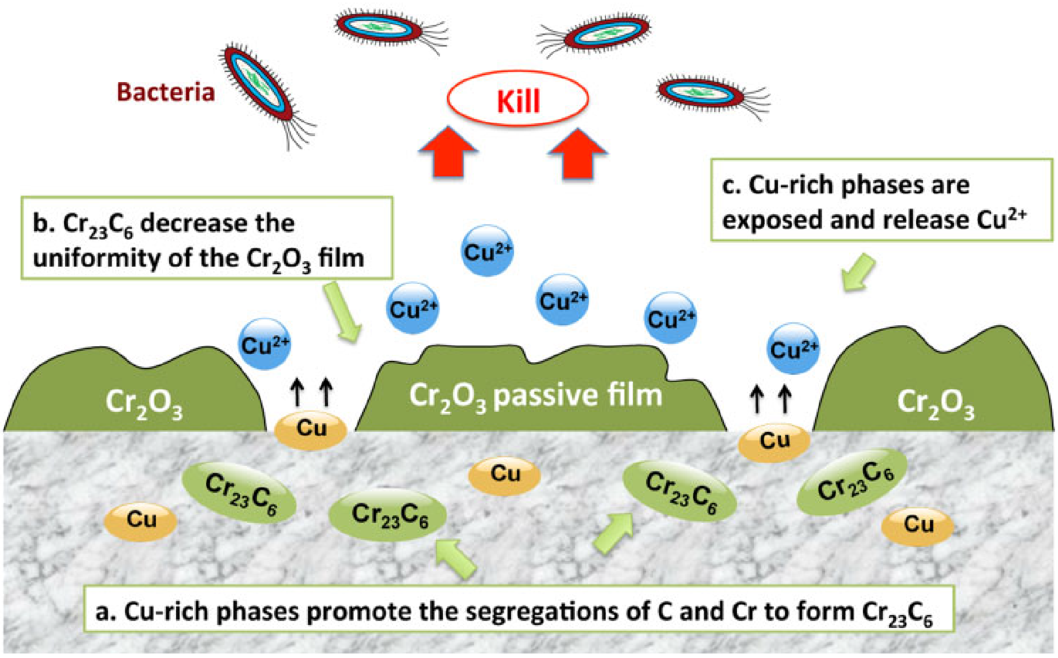


Figure 3.2: Cu^{2+} effect on Stainless Steel surface

Copper and lots of copper alloys are registered at the US Environmental Protection Agency because the first solid antimicrobial material and this has moved copper to the middle of infection control.
Copper and silver have shown similar rates of killing by contact, actually silver is well recognized as an antibacterial metal and is already in widespread use as an antibacterial agent, mainly in colloidal form.
Based on current knowledge, it appears that two conditions must be met for a metal to be antimicrobial:
- To possess a redox-active surface under ambient conditions
- To release ions toxic to living micro-organisms.
Silver features a standard reduction potential of 0.8 V for the Ag/Ag^{+} couple, and copper has reduction potentials of 0.52 and 0.35 V for the redox couples Cu/Cu^{+} and Cu/Cu^{2+}, respectively. These reduction potentials are within the range of biological reduction potentials, and it are often speculated that the redox-active metals disturb the cellular redox chemistry or catalyze destructive reactions at the cell surface. Iron covers a variety of redox potentials, namely, 0.41 V for Fe/Fe^{2+}, 0.04 V for Fe/Fe^{3+}, and 0.77 V for the Fe^{2+}/Fe^{3+} redox couple. The Fe^{2+}/Fe^{3+} redox potential is within the range of these of silver and copper, and it appears feasible that it's this redox chemistry that causes membrane damage. If copper ions also are present, they're going to effect the intracellular damage resulting in contact killing.

The way bacteria are killed on copper surfaces is poorly understood; especially, it's not yet clear whether the killing by contact proceeds mainly through dissolved copper ions and therefore the resulting cell damage or whether the contact of the bacteria with the copper surface is a crucial think about the method.
Depending on the sort of copper coordination to the protein, the redox potential of copper can range from +200 mV to +800 mV, and therefore the redox properties of copper also can cause cellular damage.
First, it's been found that living micro-organisms equipped with upregulated copper resistance mechanisms are more immune to killing by contact, while bacteria lacking in copper resistance systems are more easily killed by metallic copper; secondly, it's been demonstrated for several bacterial and fungal species that enormous quantities of copper ions enter the cytoplasm and their toxicity has generally been attributed to their ability to catalyze Fenton chemistry consistent with the reaction [34; 35]:

$$Cu^{+} + H_2O_2 \rightarrow Cu^{2+} + OH^{-} + OH\cdot$$

The hydroxyl can participate in numerous harmful reactions to cell molecules, like protein and lipid oxidation and copper ions also can cause the depletion of sulfide acids, as in cysteine or glutathione, during a cycle between the subsequent reactions:

$$2Cu^{2+} + 2RSH \rightarrow 2Cu^{+} + RSSR + 2H^{+}$$
$$2Cu^{+} + 2H^{+} + O_2 \rightarrow 2Cu^{2+} + H_2O_2$$

The peroxide thus generated can successively react again and cause the further generation of toxic hydroxyl radicals. An alternate route of copper ion toxicity has been shown to be the displacement of iron from iron-sulfur clusters, where similarly, copper ions can compete with zinc or other metal ions for important protein binding sites.
On the opposite hand, the Felton reaction combined with the Haber-Weiss cycle, can provide an upscale source of reactive oxygen species (ROS), which may produce large amounts of hydrogen peroxide:

$$H_2O_2 + OH\cdot \rightarrow H_2O + O_2^{-} + H^{+}$$
$$H_2O_2 + O_2^{-} \rightarrow O_2 + OH^{-} + OH\cdot$$

The ROS generated by these reactions can cause irreversible damage of cellular components and may also inhibit the respiratory chain or divert electrons from it, resulting in further production of ROS.

The antibacterial functions are obtained for stainless steels through the addition of an excessive amount of element Cu, 1-2%, which has the function of killing bacteria and precipitates as a sort of small phases rich in Cu with nano-sizemeters within the steel matrix at high temperatures. Therefore, Cu is that the key element

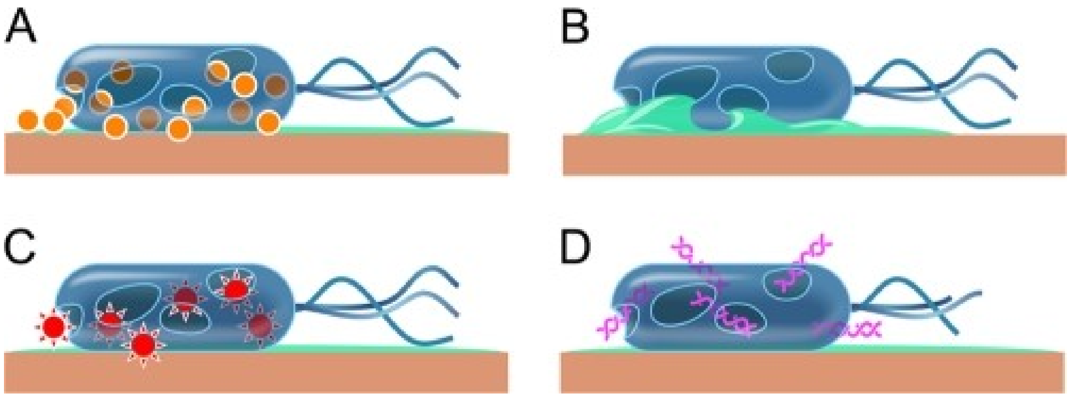


Figure 3.3: Anti-microbial activity of Copper

liable for the antibacterial function of antibacterial stainless steels. However, the addition of excess Cu may cause the precipitation of rich Cu with a lower freezing point within the hot-working temperature region in steels, which can damage the hot-working performance of steels. Additionally, an excessive amount of Cu precipitation also features a negative effect on the corrosion resistance of stainless steels. Therefore, there should be an optimal range of Cu content in any antibacterial stainless steel, so as to form the steel to possess not only the actual antibacterial functions but also good combinations of mechanical properties, corrosion resistance and hot workability [34; 35].
Although some organisms have mechanisms of resistance to excess copper, generally, the exposure of most microorganisms to high concentrations of this chemical element causes damage to cellular components. Viruses lack DNA repair mechanisms, permeability barriers, intra- and extracellular metal seizure by cell envelopes, active metal transport membrane efflux pumps and enzymatic metal detoxification mechanisms, like those found in bacteria and cells. The reduced capacities of viruses can therefore explain their high vulnerability to copper.
Copper are often a strong weapon within the fight against COVID-19 and future pandemics, but we must use it. With the arrival of antibiotics, the worth of copper as a medical treatment was put aside and lost from our collective knowledge domain. While the planet focuses on the treatment of COVID-19 patients and therefore the development of test kits and vaccines, prevention will soon be more important.
The anti-coronavirus activity of copper halos probably extends to all or any coronavirus strains because this class of virus is actually structurally identical. We've all familiarized ourselves with the spherical shape of the coronavirus with its protruding tips. The RNA of the virus is contained during a spherical "envelope" composed of lipid molecules (fatty acids) arranged during a double layer or bi-lipid layer, which protects it. Within this double lipid layer are two viral proteins, E and M. a third protein, the S, or "spike" protein, is anchored at one end within the lipid

layer and projects to the surface of the surface as radial spikes. These spikes give this group of viruses their name because they resemble a "corona" when viewed at high magnification.
Small variations in hereditary information (RNA) produce slight variations in proteins exposed on the outer surface that are liable for attack and entry into respiratory cells where RNA uses host cell metabolic machinery to supply other viruses. Variations within these proteins don't produce significant changes in the general structure and performance of the virus. Thus, it are often assumed with an inexpensive degree of certainty that the effectiveness of copper alloys against new variants should be observed [39].

3.2 Precipitation of *Cu*

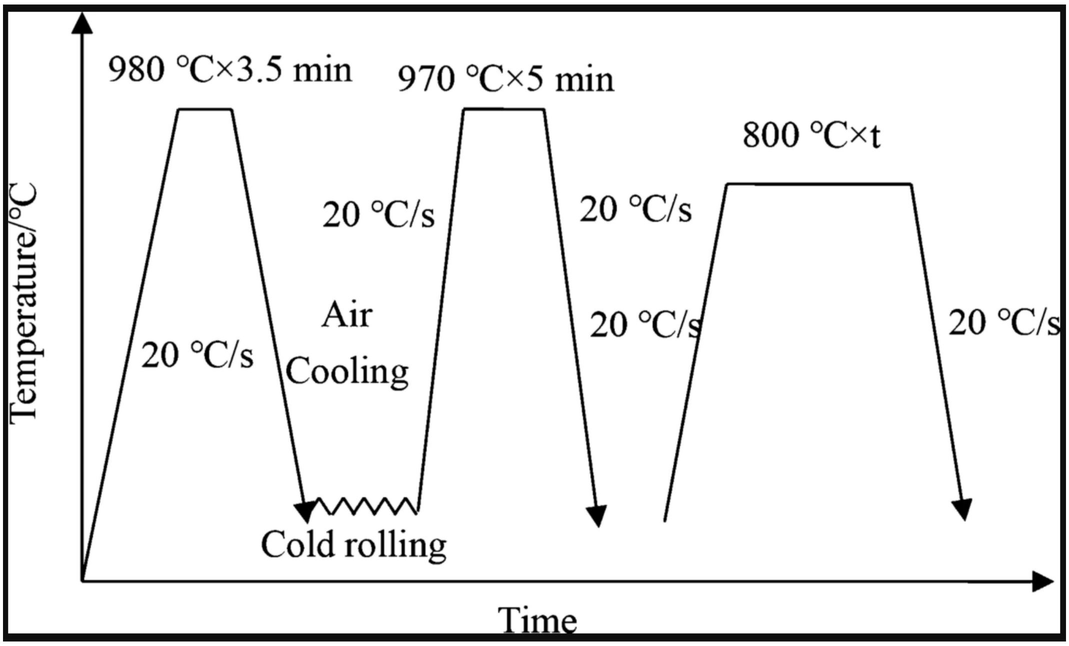


Figure 3.4: Heat treatment schematic

The precipitation of an adequate amount of Cu phase is that the key to the antibacterial performance of antibacterial stainless steel containing Cu. Precipitate hardening, or the second-phase particle strengthening mechanism resulting from heat treatment, plays a crucial role in modern alloys. The strengthening effect of those particles may result from their consistency with the matrix, inhibition of dislocation slip, inhibition of grain boundary slip, also because the obstacle to recovery processes thanks to the pinning of the network of dislocations. It's been demonstrated that, with the acceptable selection of heat treatment parameters, it's possible to regulate the precipitation of the hardening phase and, therefore, modify the ultimate mechanical and functional properties.
The energy of activation of Cu diffusion in ferrite is 284,000 J/mol. When the steel annealing temperature is high, the dislocation isn't the most nucleation core of the Cu precipitation phase; instead, the homogeneous nucleation is that the main mode of the copper precipitate within the ferrite matrix. When the Cu precipitated nuclea evenly within the matrix, a spherical nuclear embryo of diameter d is made. The driving force is the free energy of phase transformation, ΔG. Its value has been calculated using the subsequent formula [44]:

$$\Delta G = \frac{1}{6}\pi d^3 \Delta G_V + \frac{1}{6}\pi d^3 \Delta G_{EV} + \pi d^2 \sigma$$

Where ΔG_V is that the phase change free energy per unit volume. ΔG_{EV} is that the elastic strain energy per unit volume caused by the formation of a replacement phase, and σ is that the specific interface energy between the second-phase and therefore the matrix.

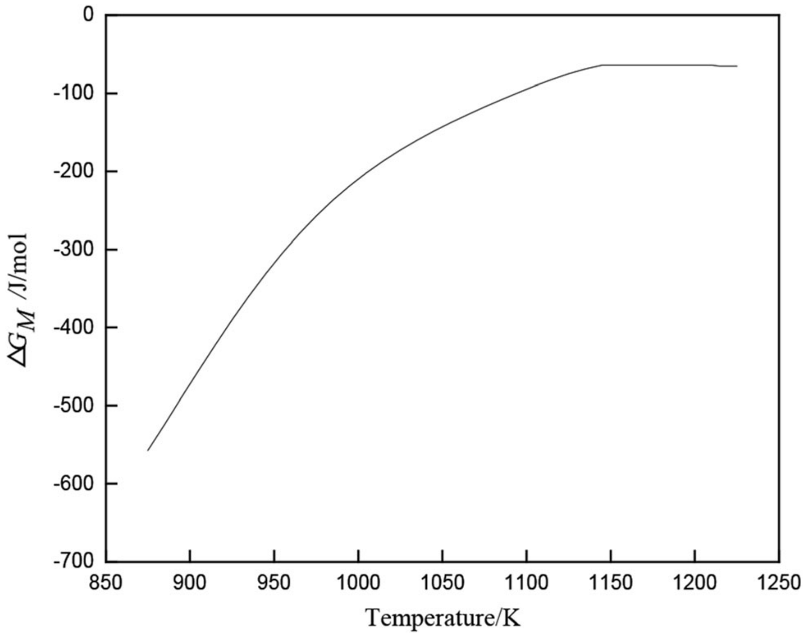


Figure 3.5: Diagram $\Delta G_M - T$

The relationship between molar volume and temperature are often calculated by using the formula:

$$V_M = 4.933 \cdot 10^{-10} T + 6.9276 \cdot 10^{-6}$$

The critical nucleation work ΔG^* are often expressed as:

$$\Delta G^* = \frac{16\pi\sigma^3}{3\Delta G_V^2}$$

The nucleation rate I are often expressed as:

$$I = K d^{*2} \cdot e^{-\frac{\Delta G^* + Q}{kT}}$$

$$\lg \frac{I}{K} = 2 \lg d^* - \frac{\Delta G^* + Q}{kT} \frac{1}{\ln 10}$$

Where K may be a constant independent of temperature, k is that the Boltzmann constant with units J/K, and Q is that the energy of activation of dominant atom migration.

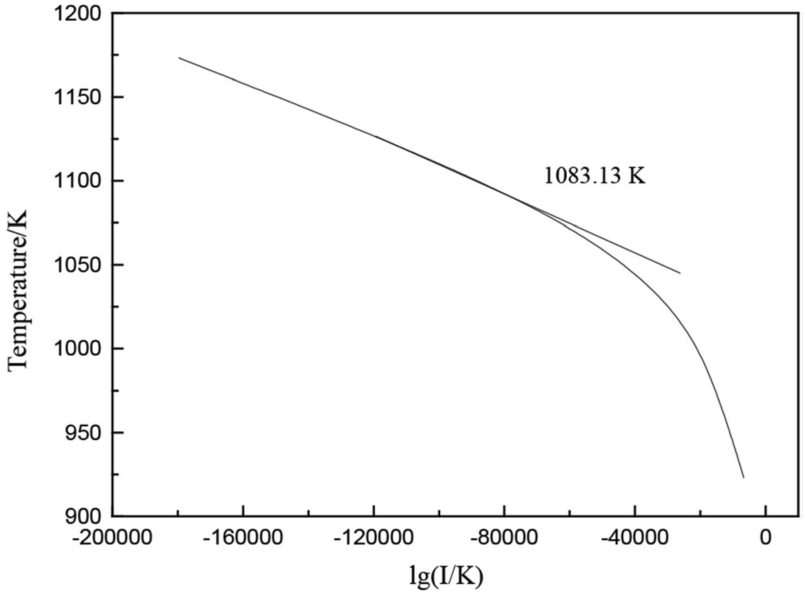


Figure 3.6: Diagram $T - \lg \frac{I}{K}$

The difference between the relative nucleation rate and therefore the absolute nucleation rate is merely a continuing term; thus it's that the nucleation rate at different precipitation temperatures are often determined by the connection diagram $T - \lg \frac{I}{K}$

The graph 3.6 shows that the speed of nucleation decreases monotonically with the rise of the annealing temperature; when the temperature is below 1083,13 K (809,98 °C), a decrease in temperature corresponds to a rise within the sensitivity of the nucleation rate to temperature. In contrast, the variation within the nucleation rate of the Cu precipitate remains unchanged as temperature changes when the temperature is above 1083,13 K [44].

Nucleation of Cu precipitates is decided by two factors, the primary is that the diffusion coefficient D of Cu atoms, the second is that the change of the ΔG phase transformation free energy within the Cu precipitate. The diffusion coefficient of the Cu atoms increases because the annealing temperature increases, which shortens the nucleation time of the Cu precipitates; however, upper the isothermal temperature is, lower the degree of supercooling is and therefore lower the difference in free energy is, as a result, the nucleation time of Cu precipitates increases.

The figure 3.7 shows that with the rise within the annealing temperature, the nucleation time of Cu precipitates increases monotonically. This result indicates that the most factor influencing precipitation kinetics is that the change of the free energy of phase transformation of the Cu precipitate in stainless steel, while the diffusion coefficient of the Cu atoms is a smaller amount important [44].

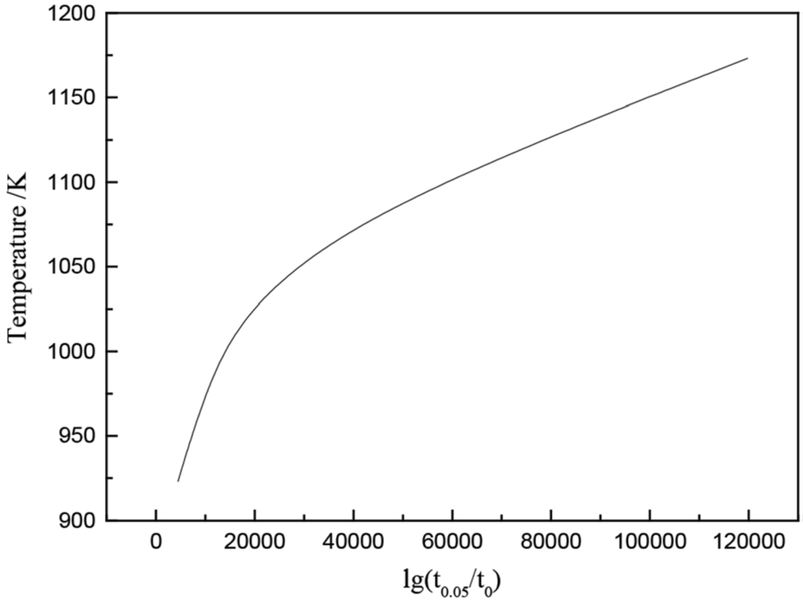


Figure 3.7: Diagram $T - \lg \frac{t_{0.05}}{t_0}$

The main factor influencing the antibacterial performance of antibacterial stainless steel is that the size of Cu precipitates. The rise in ageing time has led to a rise within the size of the copper precipitates and a decrease within the density of the number; additionally, with the rise within the ratio, the form of the precipitated phase changed from an initial spherical form to an ellipsoidal form and eventually to a stick shape. The rise in annealing time improves the antibacterial activity of the steel until it kills almost 100% of the bacteria; therefore, it's clear that the antibacterial performance is closely associated with the dimensions and therefore the total area per unit surface of the precipitate.
Figure 3.8 shows that with the increase in annealing time, the amount of colonies decreases significantly. Almost no colony was detected after annealing for quite 3600 s, which means that annealing time has a significant effect on the antibacterial properties of steel. Figure 3.9 shows that the antibacterial activity of steel increases with increasing annealing time to about 100%. Antibacterial activity is over 99%, and excellent antibacterial properties were obtained after the annealing time exceeded 3600 s [43].
The equivalent sphere size are often calculated as follows:

$$D_s = \sqrt{\frac{D_0^2}{2} + D_0 L}$$

The total area of the precipitate per 100 μm^2 of the sample was given as follows:

$$S_t = N \pi D_s^2$$

Where D_s is that the equivalent sphere size; D_0 is that the bottom diameter of the rod-shaped precipitate; L is that the length of the rod-shaped precipitate; S_t is that the total area of the precipitate on the world of 100 μm^2 of the sample; N is that the number of precipitates per 100 μm^2; and π is that the circumference ratio, which is taken into account to be 3.14 [43].

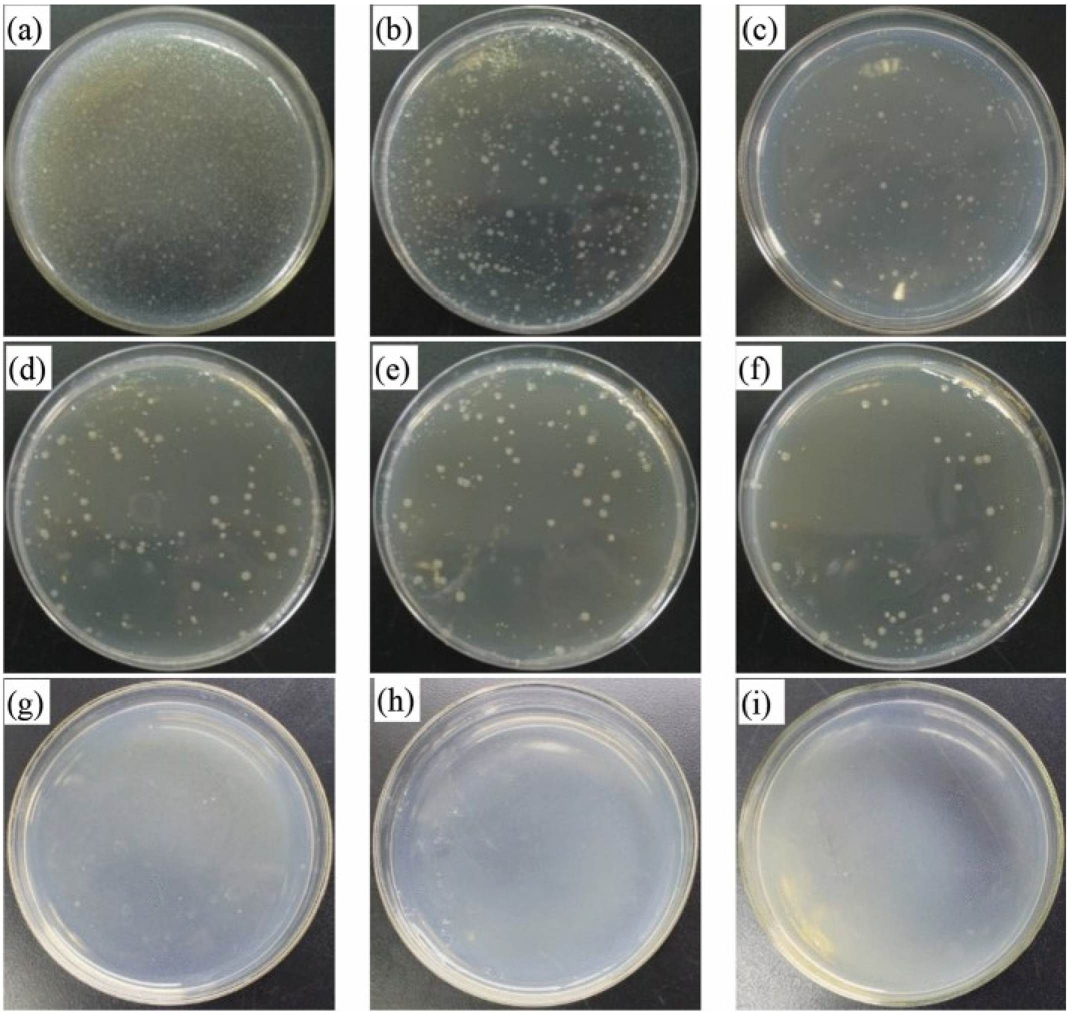


Figure 3.8: Antibacterial properties of the tested samples: (a) Negative comparison diagram and after an annealing time of (b) 0 s, (c) 60 s, (d) 180 s, (e) 600 s, (f) 2400 s, (g) 3600 s, (h) 21,600 s and (i) 36,000 s

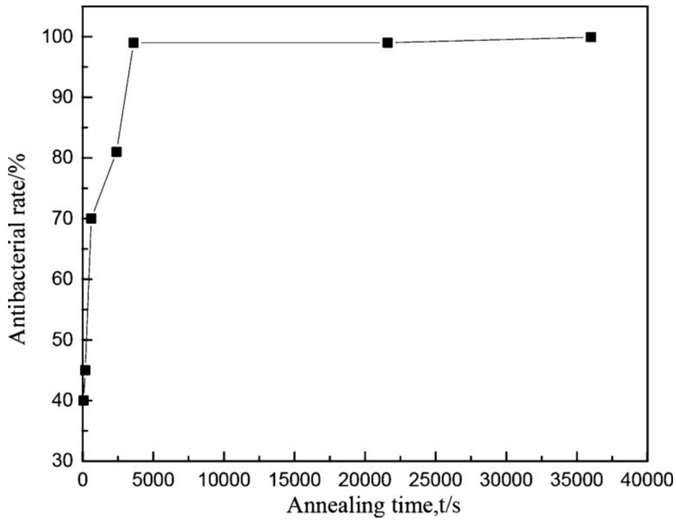


Figure 3.9: Change in the antibacterial activity with the annealing time

In several studies, stainless steel was mainly subjected to antibacterial heat treatment on the hot-rolled plate before cold rolling, for a annealing time of about 2-6 hours. Copper precipitates can dissolve during the cold rolling process, leading to a decrease in precipitate size, which is unfavourable to antibacterial properties. Copper ions (Cu^{2+}) are the shape of copper that kills bacteria, as shown within the figure. When Cu^{2+} ions enter the cell, they undergo oxidation-reduction reactions with thilase within the microorganism, then Cu^{2+} absorbs electrons and turns into Cu^{+}, while O_2 turns into O_2^-. Then, O_2^- participates during a sort of reactions with bacteria, generating free radicals H_2O_2 and OH^- that interact with the cell wall, resulting in oxidation of unsaturated fatty acids and reducer enzymes on its surface, this results in cell wall rupture and bacterial death [43].

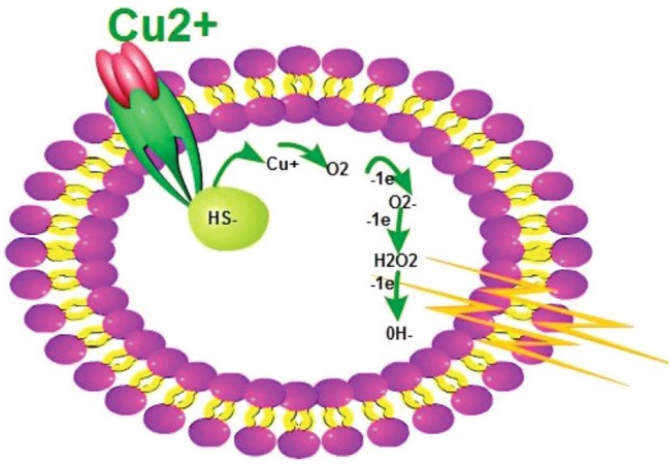


Figure 3.10: Schematic diagram of Cu^{2+} ions killing bacterial cells

3.3 Influence of Niobium

Copper is understood as an antibacterial agent; and, it's been shown that Niobium improves the antimicrobial effect of Copper by stimulating the formation of precipitated Copper particles and its distribution within the stainless steel matrix, similar effect that happens with Precipitation Hardening Stainless Steels.
Nb fairly often contributes to the resistance of a microalloyed steel beyond the expected level thanks to the strengthening of the grain size resulting from thermomechanical processing. Two different mechanisms are at the basis of this phenomenon, and both need to do with the quantity of Nb that is still in solution after hot rolling; the primary is that the increase in hardening of the steel thanks to the Nb, and therefore the second is that the fine precipitation of NbC in ferrite and austenite [37].
The addition of Niobium to steel leads to the formation of Niobium carbide (NbC) and Niobium nitride (NbN) within the steel structure. These compounds improve grain refinement, retardation of recrystallisation and hardening by precipitation of steel, which increase the toughness, strength, formability and weldability of microalloyed steel.
Niobium is a component that has no antibacterial characteristics in itself, but is vital to enhance the antimicrobial effect of Copper because it stimulates the formation of precipitated copper particles and its distribution within the stainless steel matrix [38].
Small additions of Niobium increase the strength of low-carbon steels by combining with carbon to make a dispersion of NbC precipitates. NbC precipitates are cubic with centered faces and may form both within the austenite matrix, at the austenite/ferrite interface during transformation from austenite, γ, to ferrite, α, or ferrite matrix during cooling or subsequent aging. The rise in resistance results from both grain refining and precipitation hardening. NbC precipitates that form within the austenite matrix act to dam grain boundaries and stop excessive grain growth, thus reducing the general size of ferrite grain and giving a strengthening of Hall-Petch. Cooling reduces the solubility of Nb and C and precipitates a fine dispersion of carbides inside the ferrite, both during and after transformation from γ to α, giving a strengthening by precipitation.
The first-order nucleation and rate of growth models for precipitation of NbC and cubic inch the ferritic phase of a stainless steel, are developed using classical theories for homogeneous nucleation of coherent and spherical precipitates and therefore the growth of a nucleus of critical dimensions, given by the equations [45]:

- Nucleation Rate:

$$N_V = KDe^{\frac{A\sigma^3}{\Delta G_V^2 kT}}$$

- Growth Rate:

$$\frac{dr}{dt} = \frac{D(C_0^\alpha - C_e^\alpha)}{r_0(C_e^\beta - C_e^\alpha)}$$

where K and A are constant ($K = 10^3 4 \times C_0^2$; $A = 16\pi/3$), D is that the diffusiveness of the solute element that controls the speed in iron, k is that the Boltzmann constant, σ is that the interracial energy, ΔG_V is that the volumetric escape energy that comes with both tension energy and chemical free energy, T is that the temperature, r_0 is that the critical radius beyond which the nuclei begin to grow and is adequate to $2\sigma/\Delta G_V$, C_0 is that the solute equilibrium concentration, $C_0^\alpha - C_e^\alpha$ is over-saturation and $C_e^\beta - C_e^\alpha$ is that the difference in concentration across the interface between matrix and precipitate.

Although *NbC* particles are inchoerent in Fe, it's believed, through studies done, that *NbC* initially precipitates as coherent nuclei and becomes inchoerent with subsequent growth. The deformation energy between the *NbC* precipitates and therefore the ferrite matrix has been neglected since the *NbC* nucleates with a special orientation relationship along a plane of habit that minimizes the deformation energy. The nucleation and growth of *NbC* precipitation depends on the slower-spreading species, hence Nb.
The austenization temperature greatly influences the nucleation and growth kinetics of *NbC* by altering the equilibrium concentrations of solutes for Nb and C. The very best rates of nucleation and growth are achieved for the very best temperatures of austenization thanks to the very best concentrations of Nb and C in austenite. More Niobium and Carbon in solution at high temperatures are associated with higher supersaturations and changes in free volume energies at the time of cooling, making nucleation and precipitate growth easier.
Prolonged ageing produces an initial increase in hardness when the Copper precipitates grow to the optimum size, followed by a continuing tightness or a gradual decrease in hardness when the Copper precipitates begin to oversize, counting on the temperature of austenization. For lower austenization temperatures (900-1000 °C), the reduced solubility of Nb and C in austenite reduces the quantity fraction of *NbC* precipitates and slows down precipitation kinetics, thus reducing the effectiveness of *NbC* to catch up on over-aged Cu precipitates [45].
The industry today is very concerned about the antibacterial properties, even more after COVID19, and metallurgical development of alloys is only one variable of this equation. When the current global crisis has subsided, efforts should be directed towards future preventive measures. Nanocoatings demonstrate high efficacy against bacteria, molds and viruses and have also demonstrated greater efficiency than previous technologies as they can work on multiple levels at the same time: antiviral, bacterial and self-cleaning. Cooper itself has proven that its already a consolidated

solution to control bacteria growth and Niobium addition has been showing good potential to increase even more the performance.

3.4 Strategies for Improving Antimicrobial Properties of Stainless Steel

- Surface Chemistry

By modifying surface chemistry, scientists have struggled to enhance the effectiveness of antibacterial activity embedded amicrobic agents in stainless steel coatings. Although these approaches have generated improvements, they're complex and have variety of severe limitations.
In addition, surface finishing methods, like electropolishing, are described as evoking an area inflammatory response that makes a perfect medium for bacterial colonization. To supply the specified strength, metal alloys are often coated with biochemical materials that increase the corrosion resistance of the plant surface on a metal substrate. Improving the corrosion behaviour of stainless steel therefore improves the biocompatibility of metal implants in medical applications.

- Nanostructure

Recent studies have shown a greater interest in biomimetic/nanostructured surfaces, on which necrobiosis is caused mainly by rupture of the microbial membrane through cell adhesion, and, several studies argue that nanostructuring is critical in improving antimicrobial resistance. The influence of electropolished surfaces of stainless steels on bacterial adhesion has shown that nanoscale surface topographies inhibit bacterial adhesion and microcolonia formation.
This mechanism occurs because when the bacterial membrane is subjected to mechanical stress, it results in the stretching of the membrane, to rupture and eventually to necrobiosis, however, a transparent understanding of the underlying biocidal mechanism remains unknown. The antibacterial effects of stainless steel has also been improved by the "nanocavitation".

- Wettability and Surface Energy

The surface characteristics of the fabric, including:
- Surface roughness
- Surface free energy
- Angle of contact with water
- An ultra-fine grain structure
- An appropriate chemical composition of the surface

help increase the antibacterial activity of materials.

Surfaces with unique surface characteristics like wettability show microbial resistance through the antifouling effect, intrinsically surfaces form a barrier between bacteria and materials and stop direct contact. However, the mode of action of the superhydrophobic surfaces to scale back bacterial adhesion isn't yet clear.

- Plasma Technologies

The surface treatment with gaseous plasma changes the chemical composition of the surface, customizing it consistent with specific needs, and can also influence the morphology of the surface, increasing the roughness on a nanometric scale. The mixture of both chemical and physical changes increases the free surface energy of the plasma treated surface, causing the surface wettability to vary. Additionally, plasma modification only alters the surface layer of the fabric and keeps the mass attributes of the fabric intact.
Plasma is that the fourth state of matter, also called excited gas, highly reactive and electroconductive which consists of a spread of charged particles with the power to vary the surface characteristics of various materials, including stainless steel.
Researchers try to implement different plasma techniques to enhance the antibacterial surface characteristics of stainless steels without changing its desirable mass characteristics. The prevailing idea is to enhance the surfaces by coating them with silver or copper ion doped coatings, precisely for his excellent antibacterial characteristics.

Chapter 4

MANUFACTURING PROCESSES

Stainless steel has competitive advantages over other materials; in one hand, it's more immune to oxidation, corrosion and warmth than other metals, and on the other hand a better resistance to temperature and high compared to alternative options. The low maintenance that stainless steel needs and its attractive appearance along side its unique properties make it one among the primary choices to be used in any sort of function.
As mentioned above, in recent years, the increasing incidence of healthcare-related infections and therefore the excessive use of antibiotics have led to a robust demand for medical devices with antimicrobial coating. Surgical site infections are one among the foremost devastating complications after surgical procedures and, with the increased use of antimicrobial drugs, antimicrobial resistance is increasingly recognized as a worldwide problem. This results in the necessity for alternative strategies which will reduce the consumption of antibiotics, like the event of antimicrobial medical devices for instance, that's a promising solution.
The look for antibacterial biomaterials used for medical applications like biomedical plants and/or devices is consistently increasing; especially, efforts shall be focused on the event of latest antimicrobial surfaces and on the modulation of existing biomedical devices which will eradicate or a minimum of discourage bacterial adhesion and biofilm formation on surfaces. The look for surfaces with this "benefit" has an increasing attention especially for medical, industrial and domestic applications. The most strategy wont to obtain such antibacterial surfaces is that the application of surface coatings and/or surface modification processes, as different research has shown that the microstructures of certain geometries can reduce the surface adhesion of bacteria.[50]

Figure 4.1: Stainless Steel manufacturing

The manufacture of antibacterial surfaces by the appliance of surface coatings is feasible following two approaches; in one approach there's the discharge of a chemical or antibacterial agent from the surface of the biomedical device that targets surrounding bacteria, in another approach, antibiotic molecules are often grafted onto the surface of the device that prevent bacterial attack to the surface or kill the attacked bacteria. The manufacture of antibacterial surfaces for biomedical devices over the years has been made with various antimicrobial agents that include inorganic metal ions and organic molecules, especially metals like silver, gold, copper and zinc are documented for their antibacterial activities and are utilized in numerous applications.
Basically the manufacturing of an antimicrobial stainless steel is that the same as a typical stainless steel and there are two ways during which a stainless object are often made:

- It are often made up of pieces of crude steel that are hammered, rolled and joined.
- It are often made up of molten steel poured into a final mould-shaped product.

Which is that the most effective stainless object production method depends on what it's and what it might be used for.[51]

4.1 Stamping of Stainless Steels

Metal stamping has become one among the foremost versatile and popular manufacturing processes within the world, developments in metal stamping capabilities and automatic technologies have led to significant improvements in process efficiency. It can produce simple, intricate or complex parts in fast and cost-efficient batches, adhering to strict design specifications with a high degree of precision.
Metal stamping transforms raw sheets into finished components by the subsequent processes:

- Punching

Punching and blanking ask the utilization of a die to chop the fabric into specific forms. In punching, a piece of scrap is removed because the punch enters the matrix, forming a hole in the piece.

- Blanking

Blanking, on the opposite hand, removes a workpiece from the first material, making that removed component the specified workpiece or blank.

- Embossing

Embossing is a process to create a embossed design on a sheet, pressing the raw fabric against a mold, or passing the raw fabric through a roller mold.

- Coining

Coining may be a bending technique where in the workpiece is stamped while placed between a die and therefore the punch or press. This action causes the punch tip to penetrate the metal and leads to accurate, repeatable bends. The deep penetration also relieves internal stresses within the metal workpiece, leading to no spring back effects.

- Bending

Bending refers to the overall technique of forming metal into desired shapes like L, U, or V-shaped profiles. The bending process for metal leads to a plastic deformation which stresses above the yield point but below the lastingness. Bending typically occurs around one axis.

- Flanging

Flanging may be a process of introducing a flare or flange onto a metal workpiece through the utilization of dies, presses, or specialized flanging machinery. [52]

It is important to pick the acceptable raw materials and the maximum amount to choice the proper processing process, as each alloy has different characteristics, counting on the character and application of the workpiece.
The machines are often programmed or numerically controlled by the pc (CNC) to supply high precision and repeatability for every printed part. Electroerosion (EDM) and CAD (CAD) programs ensure accuracy. These drawings must be as accurate as possible to make sure that every punch and curve maintains a correct play and, therefore, an optimal workpiece quality. A 3D model of one tool can

contain many parts, therefore the design process is usually quite complex and time consuming.
There are three main criteria for choosing stainless steel from stamping:

1) Resistance to corrosion

Almost all grades of stainless steel have high levels of corrosion resistance, counting on its chemical composition, the resistance of stainless steel to corrosion ranges from the most atmospheric conditions to an entire range of acids, alkalis and chlorides.

2) Strength

Stainless steels offer high levels of tensile strength; when subjected to cold machining, stainless steel are often made thinner and lighter without losing any of its strength. Additionally to the present, heat treatment is an alternative choice to realize extremely high levels of resistance.

3) Cost and duration

Perhaps the most advantage of stainless steel is its durability, this metal lasts and rarely needs renovation sorts of maintenance. The mixture of such a powerful life cycle with a coffee initial cost makes stainless steel a convenient choice for nearly any application. [52]

The stamping involves the insertion of flat sheet, within the sort of a coil or of a raw piece, during a moulding press. Within the press, an instrument and a mould surface form the metal within the desired shape. Punching, shearing, bending, coining, embossing and flanging are all stamping techniques wont to shape metal. There are three main sorts of metal stamping techniques:

- Progressive stamping

Progressive molding is characterized by variety of stations, each with a singular function. During this sort of stamping, the metal strip is fed through a progressive stamping press, it's constantly unrolled from a coil and enters the press, where each station of the instrument performs a special cut, punch or bending. The actions of every subsequent station are added to the work of the previous stations, leading to a completed piece. Progressive molding is that the ideal solution for metal parts with complex geometry. These movements must be aligned precisely because the piece remains attached to the metal strip, until arrival at the ultimate station separates the newly manufactured part from the remainder of the metal. Each step of the method performs a special operation of cutting, bending or punching on the metal, thus gradually obtaining the form and style of the ultimate product desired. It's also a faster process with a limited amount of waste.

- Pressing Fourslide

Fourslide molding, or multi-slide, involves horizontal alignment and 4 tools are used simultaneously to model the workpiece. This process allows intricate cuts and sophisticated curves to develop even the foremost complex pieces. As its name implies, a fourslide has four sleds and when the fabric enters a fourslide, it's folded in rapid succession by each shaft equipped with a tool. It also features a relatively low cost, and production is fast.

- Deep drawing

Deep drawing consists of pulling a raw sheet within the die through a punch, forming it into a shape. It's called "deep" drawing when the depth of the drawn piece exceeds its diameter. This sort of forming is right for the creation of components that require different diameters and is a cheap alternative to turning processes, which usually require the utilization of more raw materials. [52]

The three common sorts of molding presses include:

- Mechanical technologies

Mechanical presses use a motor attached to a mechanical flywheel to transfer and store energy. Their punches can vary in size from 5 mm to 500 mm, and therefore the speed of mechanical pressing varies, usually between 20 and 1,500 strokes per minute. They're suitable for creating shallower and simpler parts from sheet coils. They're usually used for progressive stamping and transfer with large productions.

- Hydraulic technologies

Hydraulic presses use a pressurized hydraulic fluid to use force to the fabric. Hydraulic pistons move the fluid with a level of force proportional to the diameter of the piston head, allowing a complicated degree of control over the quantity of pressure and a more constant pressure than a press. Additionally, they're equipped with adjustable running capacity and speeds, and may typically provide full power at any point of the race. Hydraulic presses are usually used for little production cycles to make more complicated and deeper moulds than mechanical presses.

- Mechanical servant

Mechanical servo presses use high-capacity motors rather than flywheels. They're wont to create more complicated molds at a faster speed than hydraulic presses. The stroke, position and movement of the sled and speed are controlled and programmable. They're powered by a link-assisted drive system or direct drive system.

Some of the benefits of molding include lower mold costs, lower secondary costs and a high level of automation compared to other processes. One among the disadvantages of molding is that the higher cost of the presses along side the problem of manufacturing custom metal molds which may even be difficult to change if the planning has got to be altered during production. Stamping is employed in many applications, especially molding products are commonly used for household appliances and medical equipment. [52]

4.1.1 Home appliance

Figure 4.2: Stainless steel home appliance

Household appliances are increasingly made from stainless steel to satisfy the growing consumer demand for these high-end products. The utilization of stainless steel in household appliances has increased in recent years and is predicted to still grow. Almost 20% of all appliances have a stainless steel finish.
Stainless steels of the 300 series are the foremost used grades for the assembly of household appliances. The polished finish of stainless steel and therefore the high strength make it harder than steel to figure before being printed, bent or folded, and made in an appliance. Since it's easy to scratch or damage the stainless steel surface, you would like to pay extra attention to the coil processing equipment and handle this material with care.
Among the parts for little appliances we will find accessories and knives for robot blenders, grids for centrifuge, mixing bowls, passing to parts for giant appliances like hobs, washing machines, refrigerators, deep fryers, etc.

4.1.2 Medical application

Figure 4.3: Stainless steel medical appliance

With the growing demands of life sciences, metal components became an integral a part of the development of medical devices for active stimulation and surgery of diseases and pathologies. These devices face a continuing challenge of biocompatibility, as they need to be suitable for both indoor and outdoor use in fields like orthopaedics and cardiovascular medicine; for instance, bone and joint implants like the knee or shoulder are constantly evolving and need rapid prototyping of the device design to check its functionality.
Stainless steel medical device stampers are helping the industry in its rapid adaptability to new challenges and problems a day. To satisfy the high demands of health and medical operations, stampers specialise in ensuring that components align with certain requirements like easy sterilization, corrosion and wear resistance and shape retention. Through the assembly of deep-drawn components, the utilization of stainless steel alloys ensures top quality parts that retain all the important features before, during and after use.
The deep-drawn molding allows for total accuracy and precision for medical needs with customized designs and specialized modifications, pushing the industry forward within the most difficult times. Because medical devices can literally make the difference between life and death, the assembly of this equipment requires absolute perfection, one wrong component can mean a disaster.
The list of medical devices supported stainless steel includes precision tubes, wires, needles, catheters, prostheses, cutting tools and metal plates, don't forget the auxiliary objects that has got to be sterilized are going to be made from stainless steel, like trays, bowls, sinks, etc.

4.2 Welding of Stainless Steels

Most stainless steels are often welded by different welding processes including arc welding, resistance welding, beam and laser welding, friction welding and brazing; in each of those processes, the surfaces of the joints and any filler metal must be cleaned. Low thermal and electrical conductivity of austenitic stainless steel is beneficial in welding as less welding heat is required because it isn't conducted away by a joint as quickly as in steel.
An important think about welding stainless steel is to make sure that you simply have the acceptable input material, which suggests that you simply got to remember of what sort of base material you're welding, and in some situations it's not as simple as when two dissimilar metals are joined.
However, stainless steels, may undergo some changes during welding, it's therefore necessary to exercise an inexpensive degree of care during welding to attenuate or prevent any deleterious effects which will occur, and to preserve an equivalent degree of corrosion resistance and strength within the welding zone which is an integral a part of the bottom metal. [53]
The main objective in welding stainless steels is to supply a healthy joint with qualities adequate to or above those of the bottom metal, taking under consideration, however, any metallurgical changes that occur within the base metal adjacent to the weld and any differences within the metal filling the weld. In welding there are three main areas of concern:

1) Solidified welding metal, consisting of base metal and filling metal.

2) The heated area during which the bottom metal is heated at high temperatures but below the melting temperature.

3) The bottom metal which is merely moderately heated or not heated in the least. [54]

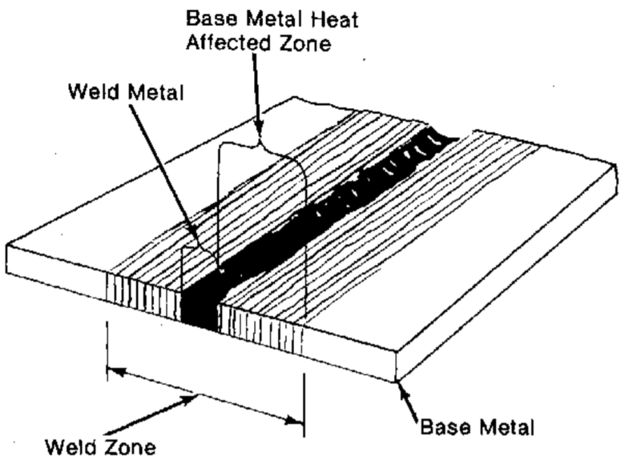


Figure 4.4: Stainless steel melted areas

The properties aren't the same for all stainless steels, but the stainless steels of an equivalent metallurgical class have an equivalent welding characteristics.

- Austenitic Stainless Steels.

Austenitic steels aren't hardenable by heat treatment and aren't magnetic within the annealed state, but can become slightly magnetic when cold worked or welded. All austenitic stainless steels are weldable with most welding processes.
Austenitic stainless steels have a thermal expansion coefficient of 45%, a better electric resistance and a lower thermal conductivity than carbon steels. High-speed welding is preferred, which can reduce heat input and carbide precipitation and minimize distortion. The freezing point of austenitic stainless steels is slightly less than the freezing point of steel and since of this and lower thermal conductivity, the welding current is typically lower.

- Martensitic Stainless Steels.

Martensitic stainless steels are hardenable by heat treatment and are magnetic. Counting on the carbon content, the low-carbon type are often welded without special precautions, while the kinds with quite 0.15% of carbon tend to be air-hardenable and, therefore, preheating and post-heat of the welds are necessary. If preheating and post-heating aren't possible, it's advisable to use an austenitic stainless steel filling metal. Welding processes that tend to extend carbon removal aren't recommended and increasing the carbon content increases the sensitivity to cracks within the welding area. Precautions to minimise the danger are:

- Use an hydrogen process.

- Preheating to about 200-300 °C consistent with welding procedure, chemical composition and section thickness.

- Perform post-welding heat treatment, at 650-750 °C, consistent with chemical composition. [54]

The welding process consists of:

1. Selection of the filler metal alloy

When both basic metals are an equivalent, use the alloy of the bottom metal as a guide. The right selection of the alloy and therefore the welding technique are therefore crucial for efficient welding.

2. Selection of welding parameters

Welding parameters should be selected to get rock bottom possible heat input to attenuate thermal distortion, which may overload the bottom materials causing stress cracks.

3. Correct preparation of joints

CONTAMINATION

Remove or eliminate all possible sources of contamination, including corrosion from products: dirt, oil, grease, incrustations, paints and marking inks which will contain chlorides. It's necessary to not mix stainless steel and steel to avoid contamination by iron as they might start localized corrosion.

MOISTURE AND BASE METAL TEMPERATURE

Remove the condensation by allowing the welds stored outdoors to heat to temperature to avoid condensation.

PLASMA CUTTING

Clean metal finish joints prepared by plasma cutting or processes using nitrogen or air within the plasma.

PREVENTION OF DISTORTION

Use frequent pins or skip welding to scale back stress and minimize weaving techniques that end in slower moving speed and increased heat input.

NARROW GAP

Avoid narrow gaps; rock bottom gap should be adequate to the diameter of the electrode.

4. Post-welding cleaning

The purpose of post-welding cleaning is to make sure a well-formed chromium oxide film on the surface for optimal corrosion resistance: the smoother the finish, the upper the corrosion resistance. The warmth of the welding is in a position to deplete the chromium at the surface, which may cause corrosion. To avoid corrosion, it's vital to get rid of the depleted area of chromium with a chemical or mechanical cleaning after welding. [54]

When welding stainless steel, it's important to watch the temperature of both the welded metal and therefore the base metal; it's necessary to remain within the required temperature ranges to avoid problems. There are 3 ways to regulate the temperature of the steel during welding:

- By means of temperature indicator rods which have good reliability in accurately confirming the temperature, however, they need limited ranges, and should need different poles for every target temperature.

- Through electronic infrared thermometers that detect the surface temperature of the steel quickly and remotely. They require a transparent line of sight, and glossy surfaces and other light-related conditions can cause false readings, also as variations in distance from the surface.

- Via electronic surface temperature probes that provide a third means of temperature monitoring. They're available with handles of various lengths that allow you to the touch the metal for a reading, and a few also can be mounted on the piece. [54]

Welding is used in many applications, especially welding products are commonly used for food industry appliances and energy industry equipment.

4.2.1 Industry appliance

When it involves industry applications, particulary in food industry, there are regulations that have an impression on every aspect of the planning, manufacture and use of kit and you would like to understand these standards well to make sure the integrity and safety of the equipment. Among these are:

- Smudges and waste must be eliminated

When working in determinated environments all microscopic burrs on surfaces must be eliminated, since keeping Ra as low as possible is that the purpose, so performing a particularly meticulous work is extremely important. This will be done through sanding, electropolishing or other specialized sanding techniques.
Burrs and spikes left on products by certain welding processes can cause injury to workers and stop productivity; therefore, the elimination of those splinters and burrs is of primary importance.

- Surfaces Must Not be Overstressed

Techniques that would cause an excessive amount of stress on the surface should be avoided, as an overloaded surface may mean that the protective oxide layer is probably going to be torn away, especially within the food field, and without the oxide layer, stainless steel is vulnerable to corrosion.
On the opposite hand, it's also necessary to avoid the utilization of any technique that would introduce stress cracks or micro-fractures into the surface of the equipment, as when the surface is subjected to an excessive amount of force or heat during welding, there could also be stress cracks resulting in corrosion.

- Dissimilar Metals shouldn't be Welded Together

For welding methods that need the utilization of a filler material to bind two metals, it's necessary, as mentioned before, the proper filler material. Just in case a filler material that doesn't react well with the metals to be welded might be used a "galvanic pair" where the difference in electrochemical potential between the filling material and therefore the metal to be welded is robust enough to make an anode and a cathode, resulting in corrosion compromising strength and integrity the simplest solution is to use a welding procedure that doesn't require a filling, or confirm that the filling material is one that doesn't create a galvanic pair with the welded metal.

A number of the risks which will occur when welding dissimilar metals are:
- Corrosion from galvanic coupling
- Thermal stress cracks thanks to different thermal capacities
- Contamination of foodstuffs by corroded surfaces

Figure 4.5: Stainless Steel Tanks And Pipes Equipment

Stainless steels have played an important role for several years in industrial sectors like oil and gas, the method industry and therefore the manufacture of chemical tanks and have also found their way into more general transport and construction applications. If wrongly welded, the potential for formation of harmful intermetallic phases increases dramatically, which could lead on to catastrophic failure. Nowadays there's a good range of grades that each one offer a beautiful combination of high strength and good corrosion resistance.
The practical application of any large-scale steel critically depends on the utilization of welding for manufacturing; productivity may be a key issue in manufacturing and, with the increased use of stainless steels, this aspect has become more important. [54]

Chapter 5

CONCLUSION AND TREND FOR THE FUTURE

The world is currently fighting a COVID-19 pandemic, and in recent years has seen SARS, MERS and a number of other flu strains per annum. Everyone causes an outsized number of victims, but, fortunately, only a couple of spread as quickly as COVID-19 which will not be the last epidemic the planet will need to face. New infectious agents will still emerge and spread throughout the planet, largely due to the high global mobility and you've got to use every available weapon to fight this endless battle. [39]
Wherever you touch surfaces which will be contaminated by bacteria, viruses and other micro-organisms that cause disease, each of those surfaces has the potential to transmit disease-causing microbes that would cause infection. The primary line of defense is frequent hand washing, but what if these common surfaces were an antimicrobial alloy?
Currently, 700.000 people die annually of drug-resistant diseases, and within the last decade approximately, the list of medicine we will use against harmful bacteria has been reduced. At an equivalent time, other disease-causing organisms are developing drug resistance that we use to fight them at almost an equivalent rate as we will create new ones.
By coating surfaces with more aggressive bactericide substances or changing their structure, some scientists hope that it will be possible to defeat infectious diseases organisms before they come into contact with humans. Surfaces and coatings that minimize the presence of active viral pathogens are studied in different environments such as health centers, transportation, schools and various companies to reduce human exposure and mitigate the spread of infectious pathogens.
The COVID-19 pandemic can function a stimulus for metallurgists to reflect on the way to contribute to public health, notes the antimicrobial activity of Cu. There's a requirement to style powerful antimicrobial stainless steels containing copper as an

economic replacement for traditional stainless steels, however obtaining an antimicrobial power like pure Cu. The alloy should contain the utmost volume fraction of nanometric Cu precipitates with as little Cu as possible so on minimize cost, avoid infragilding and increase corrosion performance.
The use of antiviral agents and coatings that have shown antiviral effects are effective in inactivating viruses on various surfaces, but still suffer from several deficiencies that inhibit their application to be used in lifestyle. Most of those methods aren't universal and their effectiveness depends on the sort of virus, plus you've got to feature the difficulties in production and therefore the cost of the fabric. [49]

Future solutions are:

- A combination of pathogenic-repellent coatings with antiviral materials could create effects through which the surface repels most viruses while coated antiviral agents inactivate those that have not been rejected, so as to have a double protection against viruses. This might significantly reduce the amount of pathogens transferred from surface to person then from person to person. Improved biocompatibility and reduced toxicity of structurally engineered repellent materials would allow them to be utilized in a wider range of applications, including the highly regulated food and medical industries.

- A combination of a spectrum of materials with different antimicrobial mechanisms should cause intelligent surfaces that attract, bind and eliminate a mess of pathogens.

- Integration of straightforward and real-time detection capabilities into these antimicrobial surfaces, also as mitigating the danger of transmission, could help identify pathogens within the environment and possibly help public health authorities to manage outbreaks of infectious diseases.

Larrouy-Maumus says: “We are surrounded by infections, so what we are fighting now is not unusual. What is very important is to get prepared for the next one that we don't know when it's coming.” [48]

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