

# Emerging Markets and Trends in the Use of Stainless Steels, Nickel-Based Alloys, and Titanium

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## Abstract

The use of Corrosion Resistant Alloys (CRAs) continues to evolve due to a number of global factors such as volatile raw material costs, material availability, environmental protection efforts, and more challenging temperatures, pressures, and corrosive environments. Thus, the selection of CRAs in their traditional roles is changing. These specialty metals are recognized for their overall value, including life-cycle cost considerations, recyclability or “green” properties, availability, and product form diversity.

World-wide market demands from the power generation market, ethanol production, oil and gas production, and transportation, high-performance components in the automotive market, and aerospace components provide a need for cost effective material solutions that are commercially available. Leaner alloy stainless steel substitution remains an area of continued interest as alloying elements such as Ni and Mo continue to drive the overall project cost of using stainless steels and other specialty metals.

This paper will describe some of the recent market trends and factors affecting material selection, and expected areas of growth for stainless steels, nickel-based alloys, and titanium used in the power generation, ethanol production, oil and gas production, transportation, automotive, and aerospace markets.

## 1 Introduction

Global economic growth is driving today’s increased demands for stainless steels, nickel-based alloys, and titanium. These metals will be referred to as Corrosion Resistant Alloys or CRAs. The responsible material specifier and engineer are faced with many different challenges today when making decisions

on material selection and process design. These include meeting budgeted project costs, adhering to stricter environmental regulations, designing for more demanding process conditions, delivery constraints, and product availability. Expensive and volatile raw material prices have forced some lower cost alloy substitutes to be more attractive. Our ever-changing global environment creates new variables that must be addressed by both the customer and by the responsible metals manufacturer.

## **2 Global Economic Growth Is Driving Material Needs**

### **2.1 Infrastructure Growth in China and India**

Infrastructure growth continues to significantly drive global demands in many end use markets that consume CRAs. For metals producers and others involved in the metal supply chain, willingness to adapt one's business model to changing input costs is necessary to provide cost competitive solutions to these growing infrastructure demands. Based on the snapshot data below, China's and India's demands will remain significant.

#### **2.1.1 Some Key Economic Data for China:**

- China's GDP is growing at 10% annually.
- China is the world's fastest growing economy and the second largest energy consumer.
- In 2006 Chinese electric power supply and demand grew at 13.5% and 14% respectively.
- The 2006 electricity generation rate of 13.5% is produced via thermal (83%), hydropower (14%) and nuclear (2%) technologies.
- Over the next 20 years, air transportation passenger volume is predicted to grow 11% annually making China the second largest aviation market that will require 1790 additional aircraft to handle.
- Airport infrastructure needs to support this growth will require 49 new airports and 701 airport expansion projects as part of China's current five-year plan which began in 2006. [1]
- Automotive production in 2005 was 5.9 million units up 14.3% from the previous year. Passenger cars make up almost one-half of this production. [2]
- An emerging middle class will offer an opportunity for an increase urban consumer spending as well a mass population shift to 100 cities that will be populated by >3 million people. [3]

#### **2.1.2 Some Key Economic Data for India:**

- India's GDP is growing at 7%.

- India is the world's second largest country by population and one of the world's fastest growing economies.
- Infrastructure requirements are expected to encompass everything from airports to container ports to teleports as the stage is being set to remake India. [4]
- Over the past decade, India has become a favorite destination for international companies to outsource IT needs. The outsourcing of engineering services has recently provided additional growth opportunities.

## 2.2 Energy Needs

World power demand continues to grow in economically advanced countries and is growing rapidly in the developing world. Future power generation sources will use a combination of conventional, renewable, and emerging technologies. Increasing emphasis will be placed on reducing emission of pollutants and greenhouse gases. Stainless steels, nickel-based alloys and titanium and titanium alloys are required in the building of new power generation sources as well as refurbishing and on-going maintenance projects.

The U.S. Department of Energy projects energy consumption in developing countries to double between 2004 and 2030, to 400 quadrillion Btu's, requiring the equivalent of (estimate) 1000 MW power plants. The non-OECD (Organization for Economic Cooperation and Development) countries are predicted to have the largest increase in energy demand due to their projected higher economic and population growth than OECD countries. Figures 1-3 demonstrate graphically the projected energy needs and use in upward trends in all fuel sources.

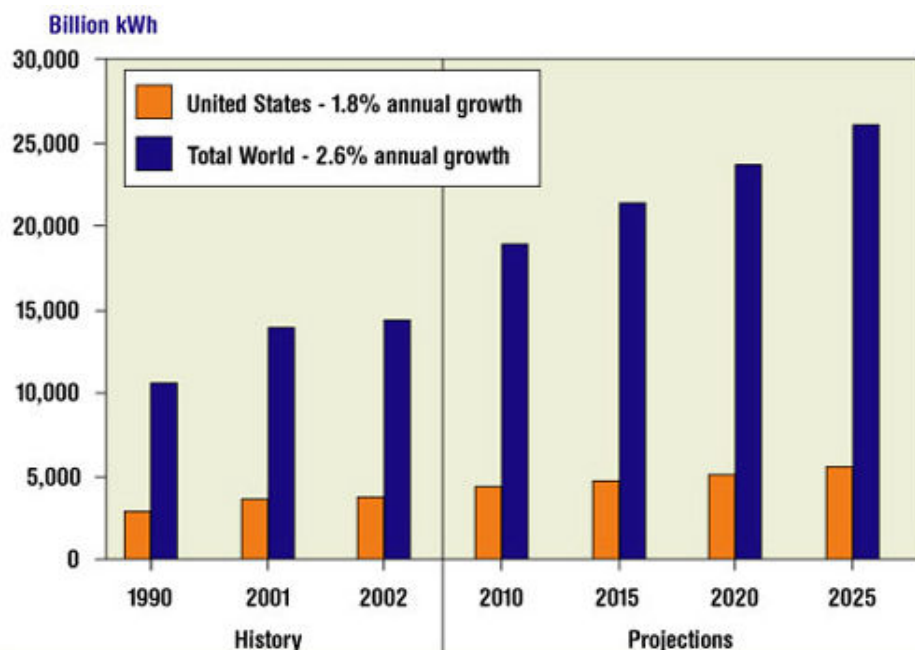


Fig. 1: Historical and projected energy needs [5]

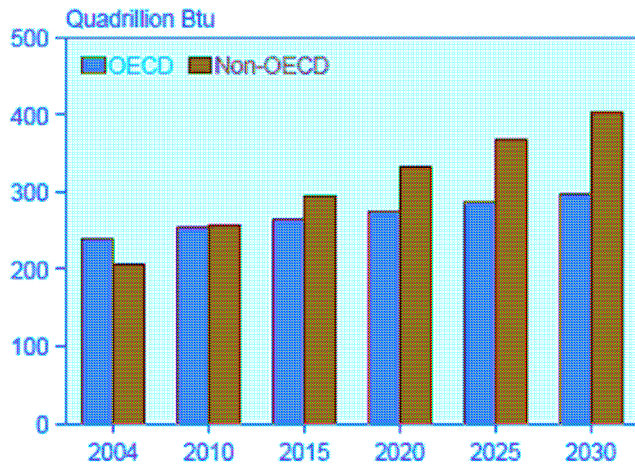


Fig 2: World marketed energy use: OECD and non-OECD, 2004-2030 [5]

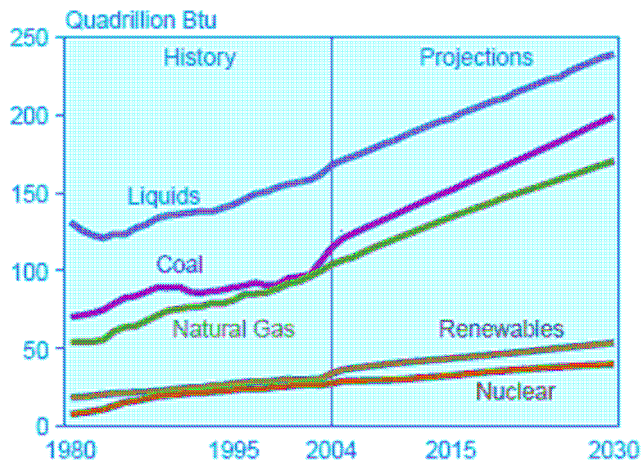


Fig 3: World market energy use by fuel type, 1980-2030 [5]

## 2.3 Raw Material Price Trends

The escalation in the price of key alloying elements for stainless steels and nickel-based alloys and for titanium raw materials is well known. Figure 4 is a snapshot view of historical yearly price averages.

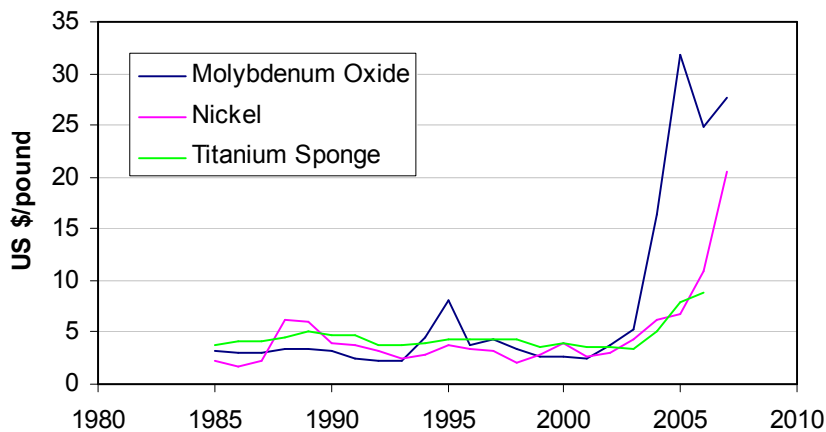


Fig 4: Yearly price averages over time [6], [7], [8], [9]

## 2.4 Being “Green”

The environments in which we all live and work contain limited natural resources which are increasingly protected. Federal, state and local levels environmental requirements now influence or mandate environmental controls and the choice of materials. The increasing generation of electric power in both developed and developing countries requires clean emissions, resulting in the need for flue gas de-sulfurization and other “green” technologies. Oftentimes, these designs require corrosion resistant alloys. The use of metals and the subsequent handling of scrap, or excess, generated during manufacturing have led to recycling often as a formal part of the supply chain. Pollution prevention requires continual awareness of the environment. Promotion of environmental awareness to observe requirements and strive for compliance is part of one’s everyday job in many of the industries where specialty metals are specified and used today.

ISSF was cited in a recent article in Nickel Magazine as reporting that in a recent survey that steel is as recycled as other commonly used materials such as paper, aluminum, and glass. Stainless steel products are reported to be recycled more than 80% of the time. In addition a product produced from Type 304 stainless steel contains 60% recycled material. [10]

Durability and long, useful lives associated with the stainless steels, nickel-based alloys and titanium and titanium alloys support global green goals.

## 2.5 Project Deadlines and Cost Containment

Many challenges continue to affect the ability of a project to be completed within budget and delivery constraints. Those involved with specifying and procuring

metal have to be able to respond effectively. The challenge with metal cost in some instances is being addressed through the offering of lower cost alloy substitutes. These substitute metals can offer lower and more stable prices often with improved strength and similar or improved corrosion behaviors. The challenge of the availability to procure the required metals in the desired product form to meet deliveries will continue to exist. Solutions continue to be more creative.

### **3 What Drives Material Selection Options and Final Decisions?**

Product cost and availability play a leading role in the material selection process. For many of the stainless steels and nickel-based alloys, the magnitude and volatility of the raw material surcharge portion of the total price has been significant. These high costs of the raw material inputs in CRAs are changing the economics of many alloys for use in many applications, presenting challenges to system designers and material specifiers. Also, the ability to procure specialty metals just-in-time (JIT) is certainly optimal though not typically feasible for all of the material options. At many service centers, the trend has been to decrease inventory and buy as-needed from the mills who are offering short lead-times. For many of the stainless steels and nickel-based alloys inventory corrections are common. As of this writing, titanium and titanium alloy lead-times and availability are improving but are still extended and

Life cycle cost analyses tools are readily available to be incorporated into decision making process as well. Many organizations which either manufacture or support the manufacture of materials offer support for use of this tool.

Energy costs, primarily related to oil and gas costs, can also affect a material decision. Many indirect costs are also associated with these costs which may impact the overall project cost. Parts that require heat-treatment may see significant price fluctuations and final part quality as the heat-treat industry in general strives to improve their productivity and contain their costs. Time and capacity constraints associated with heat-treatment also influence materials selection.

Recognition of other materials that have been traditionally alternatives and competitive materials to CRAs also play a role in material selection process. For example, other metals such as aluminum, coated and/or painted carbon steel, copper and the traditional brasses have been used with mixed success where CRAs could be specified.

Design changes that support less risk, less maintenance, fewer replacement parts, decreased inspection costs, and/or less risk for corrosion are other options that may also be considered. For example, by considering a design change to

decrease turbulence or excessive flow rates, erosion-corrosion may be minimized. This would allow copper, brass or aluminum be used. Alternatively, inherently resistant materials like CRAs could also be used. Crevices which can be potential corrosion sites should be avoided. Joints or seams can be sources of possible increased fabrication costs, inspections costs, etc. but also potential corrosion sites may be eliminated in some situations by the use of near-net shape part technology and/or prefabricated parts. As an example, powder metallurgy in near net shape forms in the high speed tooling industry has been used for many years with significant cost savings compared to traditional methods. Other advantages of the near net shape technology in this application are improved physical and metallurgical properties plus the uniqueness of being able to offer a customized chemistry for a part. The use of near-net shape technology in stamped or deep drawn sheet metal parts compared to a bar or forged block starting product that requires additional processing steps and associated costs like machining, turning, and inspection are also well known. Today, the technology within CAD, or Computer Aided Drawing, helps to lower product development costs and collapse the design cycle because users are able to create their work on a screen which can be printed, saved, and edited as necessary. Some of the useful capabilities that CAD incorporates are the output of an engineering project which incorporates important cost components like a bill of materials. [11] With such tools, material and design changes easily can be evaluated and optimized for the internal and external conditions, including important components like current full material cost including raw material surcharges.

The use of qualified third party subcontractors is also a consideration. The ability of a third party to secure specialty metals in the required product form and size at an acceptable cost can be vital in determining whether the decision has merit. Additionally, the use of third parties may also offer cost effective options like engineering services, reduced labor costs, and less work-in-process costs as material ownership may not take place until the product is delivered.

## **4 What Can a Responsible Metals Manufacturer Offer to Support Today's Demands**

A responsible metals manufacturer understands the trends and the then-current business climate. This involves understanding at all levels of the organization. The ability to create additional capacity or re-direct capacity to support demand is one way to be responsible. Manufacturer's technical assistance is also responsive. This includes identification of competitive materials to address the customer's application. A well-staffed and capable technical group plays a vital role in the support function.

## 4.1 Increasing Capacity

The demand for titanium and titanium alloys continues to be strong in the aerospace and defense markets (both jet engine and airframe), electrical energy, medical and oil and gas markets. New applications also continue to be identified. Responsible manufacturers will increase the supply base by either adding additional capacity or partnering to create additional capacity. The aerospace industry projected growth of global titanium melt capacity is documented in Figure 5.

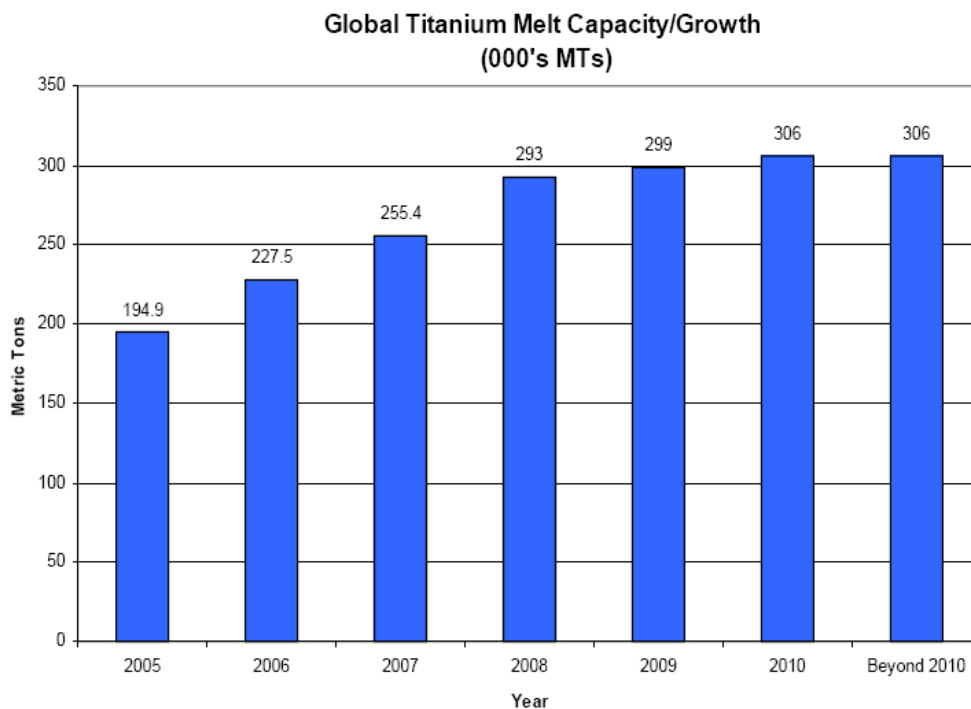


Fig 5: Global titanium melt capacity/growth in (000's metric tons) [12]

## 4.2 Alloy Substitution

In view of the rising cost of specialty metals today, the ability to offer alloy substitutes that offer at least similar if not improved material properties continues to be an area with a high level of interest. Offering alloy substitutes, supported by both technical and commercial staff, provides another level of service for a responsible specialty metals manufacturers to offer.

### 4.2.1 Duplex/Molybdenum-Containing Stainless Steel Substitutes

In environments where pitting resistance and chloride stress corrosion cracking are important a more highly alloyed stainless alloy like Type 316L or a duplex stainless steel like alloy 2205 may be required. A “switch” to a lean duplex like S32003 alloy offers economic value in purchase cost as well as filling a gap between Types 316L and 2205 duplex in corrosion resistance while providing the higher mechanical properties characteristic of a duplex stainless steel. The microstructure of a duplex stainless steel, when properly heat treated, consists of a nearly equal mixture of the austenite and ferrite phases. Duplex alloys behave in a manner that is a combination of the characteristics of both phases. This ferritic phase provides resistance to chloride stress corrosion cracking in these duplex alloys.

### Chemical Composition

Table 1 shows the typical compositions of this group of alloys. The reduced levels of chromium (Cr) and molybdenum (Mo) contents of UNS S32003 alloy make it more resistant than 2205 alloy to the formation of detrimental phases such as sigma. The lower nickel and molybdenum contents of S32003 alloy compared to the other two alloys reduce the raw material surcharge component of the price while still producing a product having high corrosion resistance excellent mechanical properties.

Alloy	UNS	Chromium	Nickel	Molybdenum	Nitrogen	PRE <sub>N</sub> *
316L	S31603	16.2	10.2	2.2	0.06	24.4
AL 2003™	S32003	21.5	3.7	1.8	0.17	30.0
2205	S31803	22.5	5.8	3.3	0.16	36.0

Table 1: Typical chemistry for more highly alloyed stainless alloys by weight %

$$*PRE_N = \%Cr + \%3.3\%Mo + 16\%N$$

### Mechanical Properties

The annealed higher tensile strength of S32003 alloy as compared to Type 316L provides the opportunity for thickness reductions and improved wear resistance. Thickness reductions up to 1/3 have been reported in some applications.

Alloy	UNS	Tensile Strength MPa(ksi)	Yield Strength MPa(ksi)	Elongation (% in 2")	Hardness
316L	S31603	607 (88)	303 (44)	57	82 R <sub>B</sub>
AL 2003™	S32003	724 (105)	517 (75)	40	20 R <sub>C</sub>
2205	S31803	862 (125)	586 (85)	30	27 R <sub>C</sub>

Table 2: Typical mechanical properties for annealed cold-rolled sheet

ASME Code Case 2503 for UNS S32003 alloy was approved by the ASME Board on Pressure Technology Codes and Standards on January 19, 2006. This code case allows the use of UNS S32003 alloy in ASME pressure vessel construction. [13] ATI Allegheny Ludlum has received accreditation as a qualified producer of UNS S32003 alloy along with UNS S31803 and UNS N08367 alloys in strip and plate products under NORSOK standard M-650. [14] The alloy also has approval under API 650. [15]

Additional material property comparisons and fabrication information are well documented. [16]

### Value Proposition

The cost savings that can be achieved with UNS S32003 is significant in both purchase price and improved properties. Figure 6 demonstrates the cost savings possibilities with UNS S32003 at current raw material levels. There is a direct relationship between the price of nickel, chromium, and molybdenum in these alloys, the weight percentage of each in the alloy, and the raw material surcharge. Because of the leaner chemistry of UNS S32003, specifically the nickel, molybdenum, and chromium, the raw material surcharge is less volatile resulting in a more stable purchase price. Because of the higher mechanical strength, there is the potential to reduce the required material thickness and thereby reduce the weight of the metals needed. Better pitting, crevice and stress corrosion cracking resistance in chloride environments are also benefits of UNS S32003 compared to Type 316L.

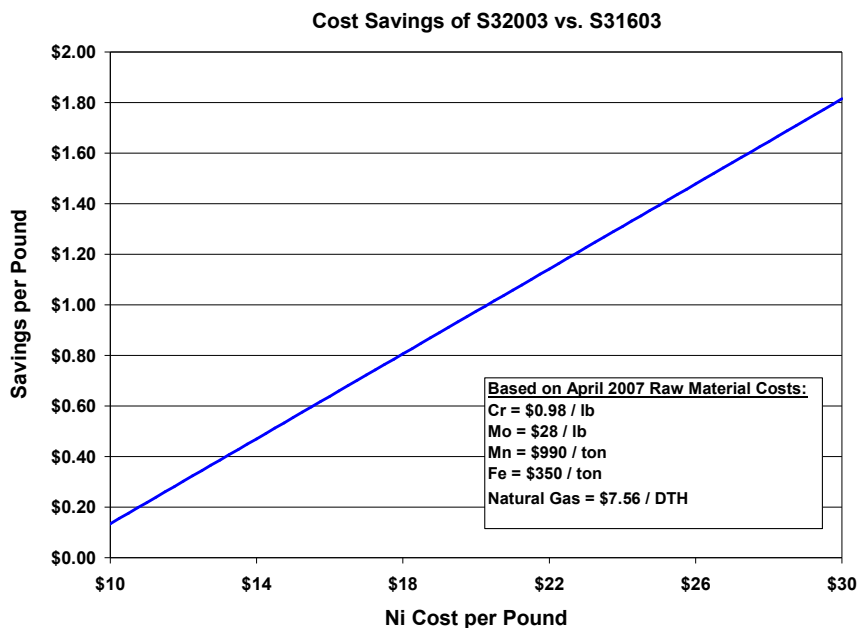


Fig 6: Cost savings of UNS S32003 vs Type 316L [16]

### 4.2.2 300 Series Alloys

Type 304 is by far the most well known and most commonly used stainless steel of the austenitic family. ATI Allegheny Ludlum's UNS S20100 and UNS S20153 alloys have seen increased use in many markets where T304, T301 or T304L are often specified. Because UNS S20100 and UNS S20153 are lower in nickel content, they offer a more stable metals cost with similar performance in most applications. Type 304 contains a minimum 8% nickel while T201 nominally has 4.5% nickel. There are other alloying elements in austenitic stainless steels that can be used to partially replace nickel without negatively impacting the corrosion resistance, since chromium is the alloying element that gives stainless steels most of their corrosion resistance. These alloying elements include manganese (Mn) which is also an austenite stabilizer. It can partially replace nickel, especially when accompanied by nitrogen (N) which can also provide strengthening. Copper (Cu) also is an austenite stabilizer. In ASTM specifications for Types 304, 301 and 201, copper is not specified. In UNS S20153 alloy, copper has a maximum limit of 1.0% by weight percent.

ATI Allegheny Ludlum's UNS S20153 alloy is a controlled composition version of UNS S20100 alloy with higher minimum nickel and nitrogen contents and is designed for sub-zero temperature service. Since customers expressed interest in using the alloy at higher temperatures, ATI Allegheny Ludlum was instrumental in the process of seeking approval for a higher maximum design temperature. Approval was granted under Code Case 2504 of the ASME Boiler and Pressure Vessel Code for a maximum design temperature of 800°F (+427°C). ASME Code Case 2504 was approved for use July 13, 2006. A corrected version, ASME Code Case 2504-1, was approved for use September 18, 2006, and was published in Supplement 11 of Code Cases. [17] Approval is being sought for API 620, Appendices Q, R, and S for ambient temperature, refrigerated, and cryogenic tanks. [18]

In addition to the 200 series alloys, there is interest in the ferritic alloys as a replacement for T304 due to the raw material price escalations. While this family of alloys does have both advantages and disadvantages over the austenitic family in technical areas, it is important to be able to identify and be able to understand the differences in choosing an austenitic vs. ferritic stainless steel alloy.

#### Chemistry

Compositions for common austenitic and ferritic alloys are listed in Table 3. These alloys are covered under ASTM A 240. [19]

Alloy	UNS	Chromium	Nickel	Manganese	Nitrogen	Carbon	Other
304	S30400	18.0-20.0	8.0-10.5	2.00	0.10	0.08	
304L	S30403	18.0-20.0	8.0-12.0	2.00	0.10	0.030	
301	S30100	16.0-18.0	6.0-8.0	2.00	0.10	0.15	
201	S20100	16.0-18.0	3.5-5.5	5.5-7.5	0.25	0.15	
201LN	S20153	16.0-17.5	4.0-5.0	6.4-7.5	0.10-0.25	0.03	1.00 Cu
430	S43000	16.0-18.0	0.75	1.00	Not specified	0.12	
441	S44100	17.5-19.5	1.00	1.00	0.03	0.03	0.10-.50Ti; .3+(9xC)min; 0.9 max Cb

Table 3– Chemical composition for common austenitic and ferritic alloys by weight %. [19]  
(maximum unless otherwise listed)

Caution: not all “201” alloys are alike. Other lower nickel austenitic alloys may be available from other producers; however, some foreign producers may not manufacture to the ASTM standards. Such materials called “201” stainless have compositions containing lower chromium, lower nickel and higher copper. Such compositions are not the same and their resulting manufacturing and service performance are not the same as products produced to the ASTM standards.

#### Mechanical Properties

As shown in Table 4 the annealed tensile strengths of UNS S20100 and UNS S20153 are substantially higher than Types 430 and 441. While the yield strengths differences are not as significant between all of the alloys listed, the elongation of the ferritic grades is in the order of magnitude of ½ that of the austenitic grades. The differences between the tensile strength and the elongation between Types 430 and 441 compared to UNS S20100 and UNS S20153 would suggest that the performance in bending, forming, and drawing would not be similar whereas similar performance would be expected compared to Types 304, 304L and 301. Practically, this would suggest that being able to manufacture a given part from a UNS S20100 or UNS S20153 and Types 304, 304L, and 301 austenitic alloys compared to Types 430 or 441 would require potential changes to the part design, the equipment used, the tooling required, etc. The differences in the work hardening behavior between Types 430 or 441 and the austenitic alloys listed here would also potentially affect the ability of the part made from Types 430 or 441 to be used with the same equipment.

Alloy	UNS	Tensile Strength MPa (ksi)	Yield Strength MPa (ksi)	Elongation (% in 2")	Hardness (RB)

304	S30400	655 (95)	310 (45)	53	85
304L	S30403	635 (92)	325 (47)	58	86
301	S30100	725 (105)	310 (45)	58	85
201	S20100	725 (105)	310 (45)	58	88
201LN	S20153	765 (111)	365 (53)	54	93
430	S43000	511 (74)	345 (50)	29	82
441	S44100	524 (76)	331 (48)	27	78

Table 4– Typical mechanical properties for annealed cold-rolled sheet

#### Weldability and Corrosion Performance

Welding of the austenitic alloys listed in Table 4 can be done using the traditional processes. These grades can also be welded to each other without galvanic attack or corrosion occurring due to their similar chemical compositions. Unstabilized ferritic grades like Type 430 are susceptible to intergranular corrosion in the heat affected zone due to chromium carbide formation. Although the chromium carbides can be dissolved and the corrosion performance restored by an annealing operation, this is not always an option for an end-use application.

Additional material property comparisons and fabrication information has been well documented. [16]

#### Value Proposition

A responsible specialty metals supplier should discuss the important material properties in addition to its sales price. Compared to Types 301, 304, and 304L, UNS S20100 and S20153 offer availability in the same products forms with similar lead-times, similar physical appearance and similar performance with respect to both manufacturing and field service performance. The difference in the mechanical properties of higher tensile strengths and higher elongations of UNS S20100 and S20153 as compared to Types 301, 304, and 304L as well as Types 430 and 441 can offer a reduction in the required thickness and associated costs.

In summary, being qualified to offer leaner alloy alternatives that offer competitive properties and less volatile prices requires commercial and technical support. To make a “switch” to a leaner alloy the metals supplier should offer support in the decision-making process through final product manufacture and field performance.

### 4.3 Technical Support

A truly responsive organization is cognizant of today’s market and demands on the customer’s staff, has a technical staff with appropriate levels of knowledge

and experience to be able to truly support the customer from product inception to commercialization. This level of support requires that the metals supplier personnel complement the customer's technical people in both the plant and manufacturing operations. This involves skills such as: understanding the technical requirements that are specified, identifying and offering possible changes in design, material, size, and metal finish, understanding availability and lead-time issues and understanding and working within regulations for the customer's manufacturing and end-use site installation.

Some examples of potential areas of support include:

- Being able to recognize and offer design choices such as –use of a thinner wall to reduce the amount of material needed, change of a joint geometry to decrease the chance of crevices becoming corrosion sites, change of a surface finish requirement to eliminate surface condition steps
- Suggesting alternative materials that - allow upfront reduced costs per pound, provide better service performance, provide extended service performance, are qualified under the governing society's specifications
- Suggesting materials produced with the latest technology that delivers high quality: internal cleanliness, tightly-controlled tolerances and materials properties and chemistry, product form which minimizes the additional processing steps required to make the final product

## **4.4 Commercial Support**

In responsive organizations there is a close relationship between the technical, management and the commercial teams. There is an understanding throughout the organization of customer need and market demands. Leadership strategies and corporate goals are crafted to drive the organization in a manner that reflects market demands, niche capabilities and financial goals. Investments in additional capacity, equipment upgrades, productivity and efficiency improvements are brought on-line where needed. Low cost energy supplies are sought. Lean manufacturing concepts are employed throughout the organization.

Formalized commercialized long-term agreements that may cover several years and many products offer commitments from both supplier and customer. Supply chain arrangements which add value can include third-party vendors can offer additional support in inventory management, and e-business concepts, for example.

International presence requires selling globally while maintaining a local presence to meet customers' needs. Local technical support as well as that from a centralized base is an effective practice to reach cross-country borders. Attendance of both technical and commercial staff members at trade shows and technical symposiums also supports international efforts.

## 5 Conclusion

Responsible metals manufacturers understand today's working environment and take responsibility for providing metal and design solutions to meet those criteria. A team of creative and talented technical and commercial support personnel are an integral part of a responsible team. Their reach must be global. And their reach has to reflect today's world and technology.

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