Current Status and Future Development Opportunities of Taiwan Superalloy Fastener Industry 台灣超合金扣件產業現況及發展契機

by Wen-Hai Liu

Introduction

Taiwan's screw and nut industry accounts for nearly 15% of the world's annual production, yet its average product price is relatively low (approximately 2.6 USD/kg), which is about 28% of that of Japan and 35% of that of Germany. Compared to the average prices of 20 global industrial exporting nations, Taiwan ranks number 19, winning only Mainland China (1.5 USD/kg). This shows that there are still many critical technological obstacles in the overall (upstream and downstream) industrial chain that need to be overcome. Taiwan's industrial fastener production technology is already quite mature and is highly competitive internationally. However, its low-price fasteners are facing competition from developing countries and losing market share. This is why the development of high-value products is such a pressing topic for maintaining the industry's competitiveness. Superalloy fasteners markets that Taiwan can enter include aerospace, energy and automotive.

Introduction of Superalloys

Superalloys indicate alloys that are ultra heat-resistant. According to the definition by American Society for Metal (ASM), superalloys generally refer to nickel-based, iron-based, or cobalt-based alloys that contain Cr in order to increase their resistance to high-temperature oxidation and corrosion, and also contain other elements (Al, Ti, Nb, W, B, Mo, Ta, Zr, etc.) in order to increase their strength under high temperatures as well as to enhance age hardening effects. Superalloys are a type of heat-resistant alloy. They are also called high-temperature alloys and can be used for a long period of time under temperatures of over 650℃ (1200° F). The range of useability for superalloys varies depending on the pressure that they need to sustain, the environmental medium, and their life span requirements.

Types and Applications of Superalloy

Nickel-based superalloys have the best mechanical properties and have now become mainstream. Although metals with high melting points, such as tungsten or molybdenum, have exhibited levels of strength under high temperatures, their usage is limited due to oxidation and can only be used under temperatures of about 500℃. On the other hand, nickel-based superalloys can be used in temperatures of around 1000℃ due to their superior strength and oxidation-resistant properties. Therefore, superalloys are widely used for high-temperature applications. Refer to **Figure 1** for a list of industries and applications in which superalloys are used. **Figure 2** shows the external appearance of a superalloy fastener for a automotive exhaust system.

1. Nickel-Based Superalloys

Nickel-based superalloys generally contain over 50 % nickel as well as 7～12 other alloy elements. At 700℃, they can still sustain 150～200 MPa (1Mpa=0.102kgf/mm2) of stress and have a life of ≧100 hours under cumbustion. Nickel-based superalloys are oxidation-resistant, corrosion resistant, and have creep temperatures of over 650℃. Their high-temperature mechanical properties allow them to retain their strength to 0.85Tm. In general, nickel-based alloys can be used in temperatures of up to 700~800℃. Casted nickel-based superalloys with single-crystal or columnar-crystal (uni-directional crystal) structures can be used in temperatures of over 800℃. The representative alloy for nickel-based superalloys is Inconel 718 of the Inconel family. The main hardening method used for nickel-based superalloys is precipitation hardening. Nickel-based superalloys can dissolve a relatively large number of alloy elements and maintain a relatively high degree of structural stability. They can also form gri-ordered intermetallic

Industry	Location of Application	Component of Application
National Defense and Aerospace	Jet Turbine Engine	Discs/Bolts/Shafts/Chassis/Blades/Burning Barrels/Afterburners/Thrust Reversers
	Space Shuttle	Rocket Engine Parts/Surfaces of Heated Areas
Energy and Electricity	Steam Turbine	Bolts/Blades/Exhaust Gas Reheaters
	Gas Turbine	Bolts/Blades/Discs/Shafts/Rings
Petrochemical and Cryogenic	Production Equipment	Bolts/Reaction Tanks/Valves/Pipelines/Pumps
Nuclear	Production Equipment	Stems/Springs/Catheters/Control Levers
Thermal Treatment	Stove-Related Components	Trays/Fixtures/Conveyor Belts
Automotive	Engine-Related Components	Exhaust Valves/Turbochargers/Engine Fasteners
Metal Processing	Heated Areas	Molds/Heating Tools and Molds
Electronics	Equipment-Related Components	Vacuum Tube Components/Electronic Components
Medical and Pharmaceutical	Dental Materials	Tooth-Filling Tools

Figure 1: Industries and Components in which Superalloys are Applied Source: Gloria Material Technology Corp.

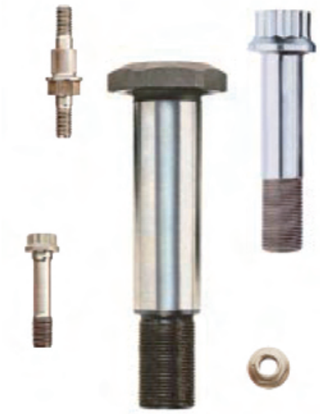	
KAMAX-Werke Rudolf Kellermann Products	INCOLOY A-286 Materials

Figure 2: Superalloy Fasteners for Automotive Exhaust Systems Source: Special Metals Corporation

compounds, allowing alloys to be effectively strengthened and to obtain high-temperature strengths even stonger than those of iron-based high-temperature alloys. In addition, nickel-based superalloys contain greater amounts of chromium, giving them superior oxidation-resistance and high-temperature gas corrosion properties, which is why they are most widely used.

Because nickel-based and iron-based superalloys contain active metal elements Al and Ti, they need to be vacuum smelted. Based on application type and composition, nickel-based superalloys are mainly divided into wrought type and casting type alloys. Wrought type alloys are mainly used under temperatures of below 816℃, applicable in turbine discs. Casting type alloys are used for application environments of 816℃ or above, such as for turbine blades or static blades (turbine airfolds). Wrought-type alloys are further divided into two types: nickel-based and nickel-iron-based. Refer to **Figure 3** for common alloy type numbers. Nickel-based superalloys possess excellent mechanical properties, including good tensility properties, fatigue properties, creep resistance, and fracture-resistance, adding difficulty to the processing of nickel-based superalloys.

Wrought type products account for 65-70% of nickel-based superalloy products, which are mainly used in jet turbine engine parts in the aerospace industry, electricity generation (including coal and nuclear), steam/gas turbine machine parts, petrochemical, marine engineering (including desalinization of sea water as well as oil drilling and exploration), environmental protection, automotive, the electronics industry, as well as heat-resistant molds, etc. The most widely used include Inconel 718 (which accounts for approximately 1/2), Inconel 625, and Incoloy 925.

2. Iron-Based Superalloys

Iron-based superalloys mainly consist of wrought type alloys, with chemical compositions of Ni , Cr, Mo, Ti, V, Mn, and Al alloys added into the iron base (Austenite). The high-temperature strength of these alloys comes from carbides ($M_{26}C$，M_6C), nitrides (Nb(C,N)), and regular lattices (γ' phase, $Ni_3(Al,Ti)$). Their hardening methods mainly consist of carbide or dielectric metal precipitation. Generally, they are used in temperatures of around 500~600℃ and have creep temperatures of above 540℃. INCOLOY A286 is the representative steel type for iron-based superalloys. After solution treatment and aging treatment, these alloy types are mainly used in the production of aircraft engines and discs for industrial turbines. They can also be used in the production of directional guidance blades, turbine blades, combustion chambers, other force-bearing parts, fasteners, petrochemical equipment, automotive turbochargers, exhaust manifolds, catalytic converters, and exhaust gas recirculation (ERG) system fasteners, etc.

3. Cobalt-Based Superalloys

Cobalt-based superalloys contain 40 %～65 % cobalt and generally also consist of 10 %～22 % nickel, 20 %～30 % chromium, as well as various amounts of W, Mo, Nb, Mn, etc. Their creep temperatures are above 650℃ and they can be applied in ultra-high temperatures (~1150℃) as well as in corrosive environments. Cobalt-based superalloys have excellent high-temperature strength and corrosion resistance. Strengthening is performed using mainly solution strengthening and carbide precipitation strengthening. Representative steel types include Hynes 188 , MP-35N, etc. Cobalt-based superalloys have better weldability and thermal fatigue resistance compared to nickel-based

Nickel-based	Nickel-iron-based
• Hastelloy S, X • Haynes 230, 242, R-41 • Nimonic 80, 90, 100, 105, 115, 263,901 • René41 • Udimet-500, 700, 720 • Waspaloy • M-252 • Astroloy • C263 • Inconel 600, 601, 617, 625, 686, 690,693, 725, 738, 740, X750	• Incoloy 800, 901, 909, 925 • Inconel 718, 706

Figure 3. Common Type Numbers for Nickel-based Wrought-type Superalloys
Source: Aerospace Industrial Develpoment Corporation

Primary Composistion (wt%)

Steel type	Ni	Cr	Nb+Ta	Mo	C	Ti	Ai	Co
718 (AMS5662)	50.00-55.00	17.00-21.00	4.75-5.50	2.80-3.30	Max.0.08	0.65-1.15	0.20-0.80	Max.1.00
718 (API6A718)	50.00-55.00	17.00-21.00	4.87-5.20	2.80-3.30	Max.0.045	0.85-1.15	0.40-0.60	Max.1.00

* Fe is reported as remainder
Figure 4. Chemical Composition of Inconel 718 Source: Gloria Materials Technology Corp.

3,000 C919's globally in the next 20 years. In the next 20 years, Mainland China will need 1000 ARJ-21 class airplanes (a production value of 30 billion US dollars), 2700 C919-class airplanes (a production value of 135 billion US dollars), and 230 military transportation aircraft (a production value of 16.1 billion US dollars). Furthermore, there is also strong demand from the energy and industrial sectors, including the electrical power generation and petrochemical industries, as well as the complete industrial chain that is being built around those industries. The aerospace-grade superalloy fastener industry in Taiwan and Mainland China are both in their infancy stages. For fastener vendors, although the aerospace industry represents high technology and high profit, it is also a supply chain that is very difficult to cut into.

Current Status of the Superalloy Industry Chain in Taiwan

1. Upstream Materials

Currently, almost all auperalloy materials used domestically must be imported, which is why Gloria Materials Technology Corp. has begun developing materials used in superalloy fasteners (such as A286, Inconel 718, Inconel 625, etc.) and has obtained material certifications as well as begun small-scale test productions. These steel types can be used in superalloy screws, nuts, and welding materials in the future.

Figure 4 shows the chemical composition of Inconel 718, which has specifications similar to those of UNS N07718 and has been priced in recent years at approximately NT 1000-1100 dollars/kg. Gloria Materials Technology Corp. can supply Φ13-200 mm bars, but 718 alloys are relatively difficult to process. Domestic wire drawing plants are not yet able to supply wire materials. Its product characteristics are as follows:

※ After going through a double vacuum smelting process (VIM+VAR), gas contents are extremely low.

※ Below 704℃ (1300℉), high-temperature yielding/tensile strength and creep rupture properties are superb. At 1000℃, it possesses excellent oxidation-resistance properties.

※ Superb corrosion-resistance, weldability, and workability.

※ 8.2 g/cm^3 density, 1260-1340℃ melting point.

INCOLOY A286 is an iron-nickel-chromium based superalloy that contains added molybdenum and titanium. Figure 5 shows its chemical composistion. Its specifications are similar to those of AISI No.660. A286 has superior medium-temperature mechanical properties as well as a simpler chemical composition and lower cost. Its price in recent years is generally around NT 500 dollars/kg (with a 20-30% premium for aerospace-grade). Gloria Materials Technology Corp. can supply Φ13-200 mm bars and can provide wire material processing services through its partners. Its product characteristics are as follows:

※ Excellent weldability and workability. Non-magnetic and suitable for medium

Primary composistion (wt%)

Steel type	Ni	Cr	Mo	Ti	Al	V	C	Si	Mn	B
A286	24.00-27.00	13.50-16.00	1.00-1.50	1.95-2.35	Max. 0.35	0.10-0.50	Max. 0.08	Max. 1.00	Max. 2.00	0.003-0.01

Firgure 5. Chemical Composition of INCOLOY A286 Source: Gloria Materials Technology Corp.

temperatures and low-stress conditions.

※ Still possesses excellent strength and corrosion-resistance at high temperatures of 704℃ (1300℉).

※ Heat treatment can be conducted to obtain precipitation strengthening effects.

※ Smelting process: average-grade (EAF+ESR) or aerospace-grade (EAF+VAR).

※ 7.93 g/cm^3 density; 1364-1424℃ melting point.

Inconel 625 has specifications similar to those of UNS N06625. It contains Ni 58%, Cr 22%, Mo 9%, Fe 5% as well as Al, Ti, Nb, Ta, Mn, etc. Typical applications include petrochemical, paper production, flue gas de-sulfurization, etc. Rods and wires are mainly used as welding materials for nickel alloys. Its characteristics are as follows:

※ Excellent corrosion-resistance to various corrosion mediums in both oxidation and reduction environments.

※ Excellent workability and weldabiltiy. No post-weld cracking sensitivity.

Gloria Materials Technology Corp. has established a set of vacuum induction smelting equipment (VIM) with one 8-ton and one 12-ton furnace. Each furnace can produce 3~4 ingots of 70~80 mm diameters each time (2~10 tons/ingot). Gloria Materials Technology Corp. will continue to expand its production facilities in Liuying Township into a high value-added (superalloy, titanium, etc.) production factory, and has plans to invest in: a 50-ton special steel production furnace, and 15000-ton closed mold forging machine, a wire production machine, as well as a 4~6 ton VIM. This will integrate its current processing capabilities, provide opportunities to further develop and integrate downstream secondary processing, as well as create even higher added value.

In addition, after China Steel successfully developed its titanium plates, titanium discs, and hot-rolled titanium film products, it is going on to developing higher-concentration superalloys. It already has many technical bottlenecks, including vacuum smelting, remelt refining, and rolling, etc. China Steel Precision Materials, a subsidiary of China Steel, has independently developed nickel-based/iron-based superalloy ingots and has shipped them back to China Steel to roll into plate and wire materials. Initial development focuses on Incoloy 800(H)/825/A286/625/C-276 alloys for the energy, petrochemical, and automotive industries, with a goal of annual production of 1,100 tons.

2. The Midstream Wire Processing Industry：

The domestic stainless-steel wire processing industry has successfully developed technologies that are already quite mature. Vendors include Walsin, New Best Wire, Yieh-Hsing, and many more. However, their superalloy wire processing technologies are not yet mature. This is even more true with nickel-based superalloys, which are stronger and more difficult to process. Kuang Tai Metal Industrial and Tientai can supply Inconel 625 bonding wire.

3. The Downstream Fastener Industry:

In terms of superalloy fastener products, Rising Fast Technology (a subsidiary of Jau Yeou Industrial), Ying Ming, NAFCO, Jamher (a producer nuts) are the few domestic companies that use imported or domestically-produced materials to produce small amounts of superalloy fasteners. The industry is currently lacking in terms of industry integration. Due to the booming development of end-user industries, such as aerospace, automotive, and energy, domestic fastener producers are constantly being asked by customers whether or not they can produce superalloy fasteners. The superalloy-related technical issues Taiwan currently faces are as follows:

(1) Formation Technologies The industry is lacking in terms of complete superalloy wire drawing and high/medium temperature forging technologies. Fasteners often use Φ5-10 mm wire materials.

(2) Molding Technologies Mold precisions need to be improved. High-class mold materials mostly need to be imported (SKD11, 61, etc.). The technological barriers come from the fact that superalloys are relatively difficult to process and work with, resulting in molds being easily damaged, thereby increasing cost of production. Therefore, the life span of molds will be the key to commercialization.

(3) Surface Treatment Technologies Electroplating quality varying from vendor to vendor, ELV environmental protection regulations, coating material patent monopolies, etc.

(4) Testing Technologies The quality of manual inspections by humans are difficult to control and high unit-price aerospace fasteners require international certification.

Taiwan's Opportunities and Challenges in Developing Superalloy Fasteners

1. Aerospace Fasteners

Fastener products used in the aerospace industry must be able to withstand extreme temperature variations, high cyclic loads, as well as repetitive vibration and stress. There are excellent prospects for these products when used in the automotive, electronic, and nuclear power industries, which require high-precision, high-quality fasteners. Superalloy fasteners and industrial fasteners are very similar in terms of production technologies and equipment. However, material, process, and quality requirements for aerospace fasteners are extremely strict and also require certification (which takes about 3 years). Once you become a qualified vendor, the quality (safety) of your products as well as your technological capabilities are very competitive. The price of aerospace-grade superalloys are as high as 2,000 NTD per kilogram, which is approximately 40 times the price of the average screw or nut. This poses as an excellent opportunity for Taiwan's fastener industry.

The aerospace screws market has gradually globallized and internationally recognized aerospace industry standards, such as AS9100. Taiwan and the United States have already signed the "Bilateral Airworthiness Security Agreement" (BASA), which means that domestic products that are inspected and certified by the Civil Aeronautics Administration in Taiwan can also obtain certification from the Federal Aviation Administration of the United States through a mutual bilateral certification recognition mechanism. Certifications can not only be used on Taiwanese airplanes, but can also be used for global brand marketing. In terms of functional testing and product verification for aerospace fasteners, in addition to the small amount of testing capabilities that fastener vendors currently possess, the ITRI Systems and Aerospace Technology Development Center as well as the Metal Industries Research & Development Center also have comprehensive aerospace fastener testing and verification capabilities, which is advantageous towards the further development of Taiwans aerospace fastener industry.

2. Automotive Fasteners

The averave car uses about 2,000~2,500 fasteners, which accounts for approximately 4.5% the car' s total weight and 2%-3% of the car' s total cost. These fasteners are mainly used in the engine, suspention, interior, and exhaust systems. Automotive fasteners are high-end products in the fastener industry, especially high-temperature resistant superalloy fasteners (mainly A286). Taiwan is already capable of supplying superalloy rod wire materials and with its internationally renowned forming technologies, heat treatment capabilities, equipment quality, mature management talent, and exceptional adaptability, it is very capable of providing high-quality services with precisely on-time delivery. In recent years, Taiwan has already attracted orders from automotive vendors from Europe and the United States, and has become the fastener production center for automobile producers in Europe and the United States. It is estimated that overall demand for fasteners in the US automotive industry will grow at a rate of 3.3%, annually.

Conclusion

One of the competitive advantages of Taiwan' s fastener industry is that it has a complete and well-functioning ecosystem of related vendors and third-party providers as well as an extremely flexible value chain. The climate of Taiwan' s domestic superalloy industry is gradually maturing and the industry' s future prospects look very promising. If vendors can advance towards the development of high-priced superalloy fasteners, they will be able to enhance their products' added value and further upgrade the industry. Looking forward, if upstream vendors can develop/replace relative imported superalloy materials, they will be able to gradually supply downstream vendors with the raw materials that they need and eliminate the need for imported materials market. Middle and downstream vendors, on the other hand, should enhance their superalloy wire drawing process technologies, develop hot/warm forging technologies for fasteners, as well as establish independent development capabilities. If upstream, mid-stream, and downstream vendors can be brought together to establish joint research and development alliances, with research accomplishments being shared and according to each vendor' s degree of contribution, the filling of industry gaps could be accelerated and products could be certified to successfully enter the global supply chain.