Overview of Fastener Heat Treatment Present & Future Direction

by Daniel H. Herring

The world market for industrial fasteners represents a 67 billion US dollar industry divided between Asia (38.2%), Europe (25.3%), North America (21.9%), and the rest of the world (14.6%).[1] Of this total the Asian market is dominated by China (14.8%) and Japan (10.1%). Last year saw strong growth in the automotive, aerospace and energy sectors and the industry is expected to show growth in the near future based on rapid global industrialization and rising demand for durable goods.

Global Industry Growth

The demand for fasteners is strong. Currently, the aerospace industry is the largest application user of fasteners, accounting for over 30% of the total fastener market. Going forward, the use of fasteners by the construction industry is poised to overtake it based on recent activity worldwide. The construction industries use of fasteners is expected to grow at a compound annual growth rate of just over 9% from 2012 to 2018.[2] Other OEM segments (e.g. fabricated metal products, electronic/electrical) have also exhibited strong growth in the last few years. The automotive sector is expected to continue to show above average growth as well in the next five years.

The Asia Pacific region accounted for the highest demand for industrial fasteners last year and is expected to account for over 45% of the market by 2018. This trend is due to factors such as rapid industrialization and favorable economic conditions, which is expected to boost the demand for durable goods and other manufacturing and development activities.

North American Industry Growth

Aerospace

The aerospace segment of the industry continues to have high demand for fasteners, especially in the commercial aircraft market, with military, missiles and space expected to see slight gains or negative growth **(Table 1).**

Table 1[1] Aircraft Sales by Industry Segment

Year	Total Sales[a]	Civil[a]	Military[a]	Missiles[a]	Space[a]	Related Products[a]	Sales Change (%)
2012	217.87	60.59	58.24	23.13	44.90	31.01	+3.4
2013	223.55	67.48	56.81	21.84	45.60	31.82	+3.0

Notes: [a] Billions of US Dollars

The Boeing Company regained its position as No. 1 in civil aircraft sales and deliveries (585 aircrafts) in 2012. Boeing is also planning to introduce several new aircrafts – the 737-MAX, the 787-9 and 787-10. Their plans call for delivery of ten 787s per month and 737 deliveries will increase from 35 to 38 aircrafts per month.

Boeing's market outlook indicates that while the demand for commercial aircraft in 2010 was 19,410 planes, by 2020 it is projected to be 28,500 planes and will continue to grow to an estimated 39,530 planes by 2030 – a 104% growth in the next 20 years with the market for the aircraft split as follows:

- Asia/Pacific – 300% growth
- N. Africa/Middle East – 190% growth
- N. America – 40% growth

It should be noted that this growth will be primarily in single and twin aisled aircraft, not in the jumbos.

Airbus is also doing well with the A320 NEO outselling the 737 by 680 aircrafts. The A350 is competing well against the 777 and 787, primarily by consuming 25% less fuel, while the future of the A380 is still in doubt despite 262 firm orders.

Automotive

The automotive manufacturing segment of the North American economy continues at a very healthy pace with sales of greater than 14.5 million units. Higher sales are anticipated in 2013 – the projection being 14.8 million units and this figure is expected to climb to 15.3 million units in 2014. It has also been projected that China will add 5 million units of new production between now and 2019 at the expense of non-German European and some Japanese production.

Sales were robust in 2012 **(Table 2)** with the automotive market share divided as follows: GM 17.9% (up 3.7%), Ford 15.5% (up 4.7%), Chrysler 11.4% (up 21%) with Toyota at 14.4%, Honda at 9.8% and Hyundai/KIA at 8.7%.

Table 2[1] Summary of North American OEM Sales

Company	2012 Sales	% Change vs. 2011	Market Share
GM	2,595,717	+3.7%	17.9%
Ford	2,243,009	+4.7%	15.5%
Chrysler	1,651,787	+20.6%	11.4%
Toyota	2,082,504	+26.6%	14.4%
Honda	1,422,785	+24.0%	9.8%
Nissan	1,141,656	+9.5%	7.9%
Hyundai	703,007	+8.9%	4.9%
Mazda	277,048	–2.0%	0.9%
Mitsubishi	57,790	–26.9%	0.4%
KIA	557,599	+14.9%	3.8%
Subaru	336,441	+26.0%	2.3%
Suzuki	25,358	–4.7%	0.2%
Mercedes-Benz	295,013	+12.7%	2.0%
Volvo	68,125	+1.3%	0.5%
VW	438,134	+35.1%	3.0%
Audi	139,310	+18.5%	1.0%
BMW	186,146	+13.5%	1.9%
Porsche	35,043	+20.7%	0.2%
Jaguar	12,011	–2.2%	0.1%
Land Rover	43,664	+14.6%	0.3%
Mini	66,123	+15.0%	0.5%
All Other	7,280	--	--

Industrial

Industrial markets are highly product dependent with most rated as “okay” to “good”, the exception being non-residential construction. In that segment the energy market did well (about 55 billion US dollars in projects) but most other construction areas have shown little growth over the last several years.

Agricultural product demand is strong paced by companies such as Caterpillar (65.9 billion US dollars) and Deere & Company (revenues up 13% over last year).

Products & Materials

Fastener applications remain as diverse as the industries they service, driven by aerospace, construction and automotive with petrochemical, nuclear, medical, marine, and mining being strong contributors.

Fastener materials cover the gambit, from ferrous to nonferrous including steel, stainless steel, tool steel, specialty grades. Coatings are also in common use and include zinc, cadmium, nickel, galvanized (hot dip, spheroidizing), phosphate and PTFE (polytetrafluoroethylene) coatings to name a few.

Heat Treat Market Size

The global heat treatment market for semi-finished goods is in the range of 65 to 85 billion US dollars[4]. The North American share is 20 – 22 billion US dollars involving some 18,000+ manufacturers.

It is estimated that China’s portion of the heat treat market is at least half of North America’s sales volume. These figures are based on an analysis of the automotive market with 14.5 million vehicles (2012) sold and the North American GDP in the range of 15 trillion US Dollars. By contrast, China manufactures approximately 19.5 million vehicles, has more than half of the US’s GDP ($8.3 trillion), and its manufacturing sector generates the equivalent of 30% of its GDP (compared to the US where the manufacturing sector only makes up around 12% of its GDP). The European Union manufactures 14 million vehicles and has the same combined GDP as the US and as such, its heat treatment volume cannot be much lower than the US.

Many countries consider heat treatment as a strategic activity and a strong contributor to their overall economy. For example, South Korea, Poland and China have significant subsidies and grants provided to furnace manufacturers that develop advanced technologies. The estimated global heat treatment equipment sales is between the range of 3.75 and 4.5 billion US dollars.[4] **(Fig. 1)**

Worldwide the number of commercial shops is estimated to be in the range of 15% **(Fig. 2)** while in North America this number is somewhat less, estimated to be in the range of 10 - 12%. Further subdivisions are possible by process **(Table 3)** and equipment **(Fig. 3, Table 4).**

Figure 1[4]
Global Equipment Sales (by dollar value)

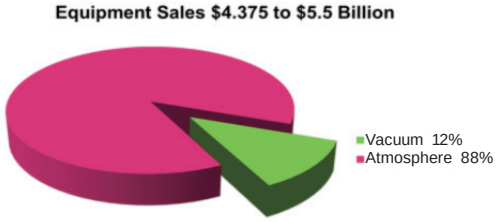


Figure 2[4]
Division of Heat Treatment Users (by dollar value)

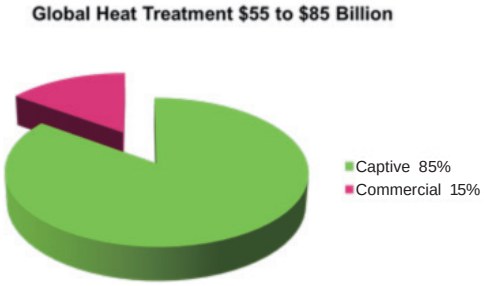
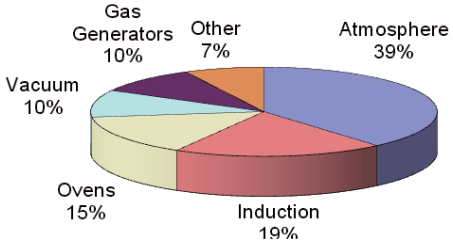


Figure 3[6]
North American Heat Treat Equipment Market
(by number of units)



Heat Treat Equipment Types

Mesh Belt Conveyor Furnaces

Today, mesh belt conveyor furnaces are the dominant technology for the heat treatment of fasteners. These units are often part of a completely automated heat-treating system that includes loaders, pre and post washers, a hardening furnace with quench tank and a tempering furnace **(Fig. 4).** Soluble oil tanks and Endothermic atmosphere generators or nitrogen/methanol systems are common ancillary items.

Heat treating systems for fasteners must be flexible enough to handle both large and small quantity demand; it is not uncommon to have production lots as small as 4.5 kg (10 lbs.) and as large as 4535 kg (10,000 lbs.) or more. Standard production capacities in mesh belt furnaces typically range from 100 kg/h (250 lbs./hr) to 3000 kg/hr (7000 lbs./hr). It is not uncommon to see fasteners loaded on the belt between 12.7 – 63.5 mm (½" – 2 ½") deep.

Table 3[5] North American Heat Treat Market (by type of process)

Type of Process	Equipment Supplied	Type of Process	Equipment Supplied
Age Hardening	3%	Nitriding	3%
Annealing	8%	Nitrocarburizing	←1%
Austempering	←1%	Normalizing	4%
Bake-Out	←1%	Other	9%
Brazing	7%	Oxidizing	←1%
Carbonitriding	2%	Physical Vapor Deposition	←1%
Carburizing	8%	Plasma Processes – other	←1%
Chemical Vapor Deposition	←1%	Quenching	←1%
Co-Firing	←1%	Reduction	←1%
Cryogenics	← 1%	Shrink Fitting	←1%
Decarburization	←1%	Sintering	8%
Deep Freezing	←1%	Soldering	←1%
Glass-to-Metal Sealing	←1%	Solution Treating	3%
Hardening	21%	Steam Treating	←1%
Homogenizing	←1%	Stress Relief	5%
Metallizing	←1%	Tempering	9%

Table 4[6]
Type of Heat Treating Equipment Supplied by Number of Units

Type of Equipment	Number of Units
Applied Energy [a]	19%
Atmosphere Furnaces [b]	39%
Miscellaneous	17%
Ovens	15%
Vacuum Furnaces [c]	10%

Notes: [a] Flame, induction, and laser
[b] Batch (48%) and continuous (52%) types.
(1) Batch styles include: box; mechanized box (e.g. integral quench); pit; bell, tip-up, carbottom; and gantry designs.
(2) Continuous styles include: cast link conveyor, mesh belt conveyors; humpback, pusher; rotary drum; rotary hearth; shaker hearth; walking beam, vibratory tube and custom designs.
[c] Batch (98%) and continuous (2%) types
(1) Batch styles include: horizontal, top loader and vertical bottom loaders
(2) Continuous styles include: carbottom, monorail, and pusher designs.

Figure 4 Typical Atmosphere Heat Treating System for Fasteners
(Photograph Courtesy of Williams Industrial Service, Inc.)

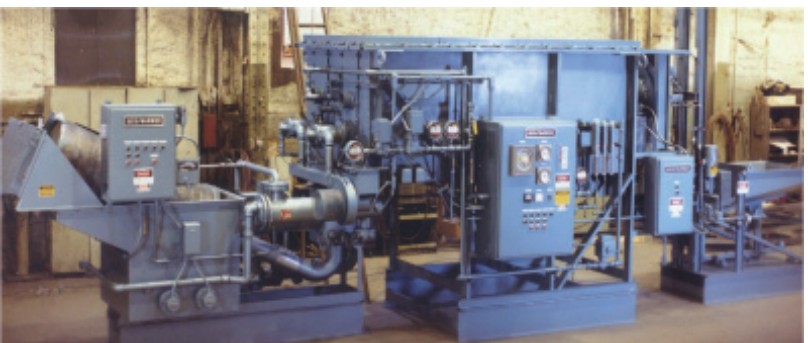
Through hardening, selective hardening and case hardening (carbonitriding and carburizing) are typical heat treat processes for fasteners. Case depths are typically shallow, in the order of 0.0038 – 0.038 mm (0.0015" to 0.015"). Quench media are more diverse ranging from brine, water, polymer, oil, and molten salt depending on engineering requirements.

Alternative Technologies

Rotary retort furnaces **(Fig. 5)** and cast link conveyor furnaces are the most common alternatives to mesh belt conveyors, usually floor mounted. The systems are typically automated and completely automatic after loading parts into the hopper at the front end. Vibratory hoppers and weight-actuated skip loaders deposit precisely measured charges into the furnace to ensure the uniform loading of parts.

Typical standard system capacities for rotary retort furnaces vary from around 225 kg/h (500 lbs/hr) to 450 kg/h (1000 lbs/hr) but can be manufactured to handle 1800 kg/h (4,000 lbs/hr) or more. The retorts are either cast or fabricated from high temperature alloys. In general, cast retorts have superior mechanical strength characteristics compared to wrought fabricated designs but often come at a cost premium. Auger flights with the retort convey the fasteners through the furnace. Variable speed rotation of the retort provides flexibility of time based processing cycles.

Figure 5 Typical Rotary Retort System with Oil, Polymer, or Water Quench Capability
(Photograph Courtesy of SECO/WARWICK Corporation)



The actual quenching process of the part is typically completed within two to five seconds from the time fasteners drop into the quenchant, with ten (10) minutes being a typical residence time in the quench for continued cooling, except for austempering processes which require extended times in the order of 20 minutes or more to produce a bainitic structure. It is critical that an adequate amount of fluid flow is delivered to the active quench area; overall quench tank capacity is not enough to ensure individual quenching of each part. The quench tank design must eliminate any clumps and clogs to assure that both proper technique and adequate quenching is obtained.

Tempering furnaces, whether mesh belt or rotary retort type, use a recirculation system designed to keep heated gases in contact with the fasteners as they progress through the oven. Convection heating is used to full advantage for efficient heat transfer in a minimum floor space. Operating temperature ranges vary from 150°C (300°F) to 650°C (1200°F).

Induction heating is also used to selectively heat treat fasteners at high production rates. For example, high frequency (10 – 50 kHz) systems can draw back bolt heads after carburizing to improve toughness at rates in the order of 1 – 2 ½ pieces/second. Similarly, seat & seat belt retention bolts, can be case hardened (200 kHz) to depths up to 0.508 mm (0.020") and surface hardness of 40 – 45 HRC to impart both strength and toughness.

Future Trends

The demand for high quality, precision processes and repeatability of part performance in ever more sophisticated and demanding service applications will result in a gradual shift from atmosphere to vacuum processing. This is also evident in many other industries; the last decade seeing double-digit growth and an increased vacuum market share throughout the Americas **(Fig. 6).** Vacuum processing is growing more rapidly than any other technology.

Continuous **(Fig. 7)** and batch **(Fig. 8)** vacuum furnace designs are common throughout the industry. For example, in the automotive industry, high volume throughput requires automated systems integrated into the manufacturing flow while in the nuclear

or medical industry, smaller discrete loads are preferred. In either manufacturing scenario, vacuum equipment is quite capable of meeting the productivity demand.

Solution annealing and aging of aerospace fasteners **(Fig. 9)** is an example of the use of batch vacuum technology. Here 17Cr4Ni (Carpenter Custom® 630) stainless steel, a martensitic precipitation/age-hardening stainless steel with high strength and excellent corrosion resistance was processed as follows:

Step 1: Solution Heat Treatment

1. Pump to 10^{-4} Torr range.
2. Heat to 1040°C (1900°F)
3. Hold for 30 minutes (based on a workload thermocouple).
4. Quench in nitrogen to 32°C (90°F)
5. Unload

Step 2: Age Hardening

1. Load furnace and pump down to mid 10-5 Torr range
2. Heat to 480°C (900°F)
3. Hold for 65 minutes (based on a workload thermocouple)
4. Nitrogen fan cool to 52°C (125°F).
5. Unload

The result is bright, shiny parts having a hardness of 42 – 44 HRC.

Figure 6[7] Vacuum Market Share

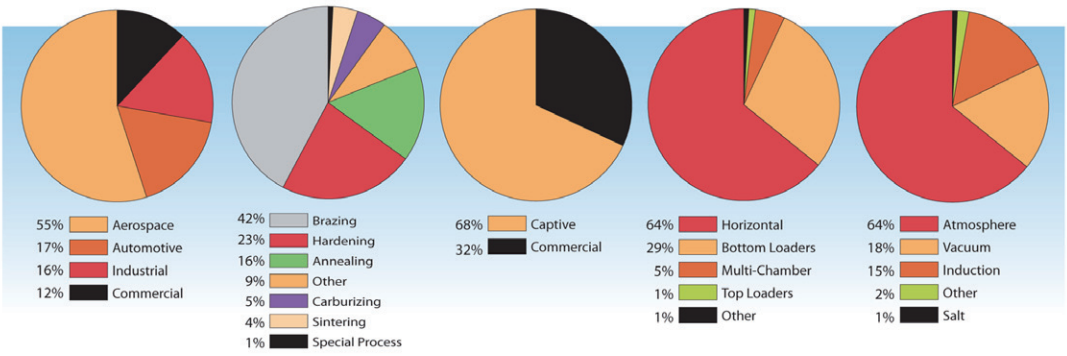


Figure 7
Typical Continuous Vacuum Heat Treat Equipment Servicing the Automotive Industry
(Photograph Courtesy of C. I. Hayes)

Figure 8
Typical Batch Vacuum Furnace Servicing the Commercial Heat Treatment Industry
(Photograph Courtesy of Solar Manufacturing)

Figure 9
Typical Load of 17Cr4Ni Fasteners for Vacuum Heat Treatment
(Photograph Courtesy of Solar Manufacturing)

Conclusion

The present and future of fastener heat treatment is vibrant, with demand for high volume production and increased quality requirements driving the industry and its future growth.

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