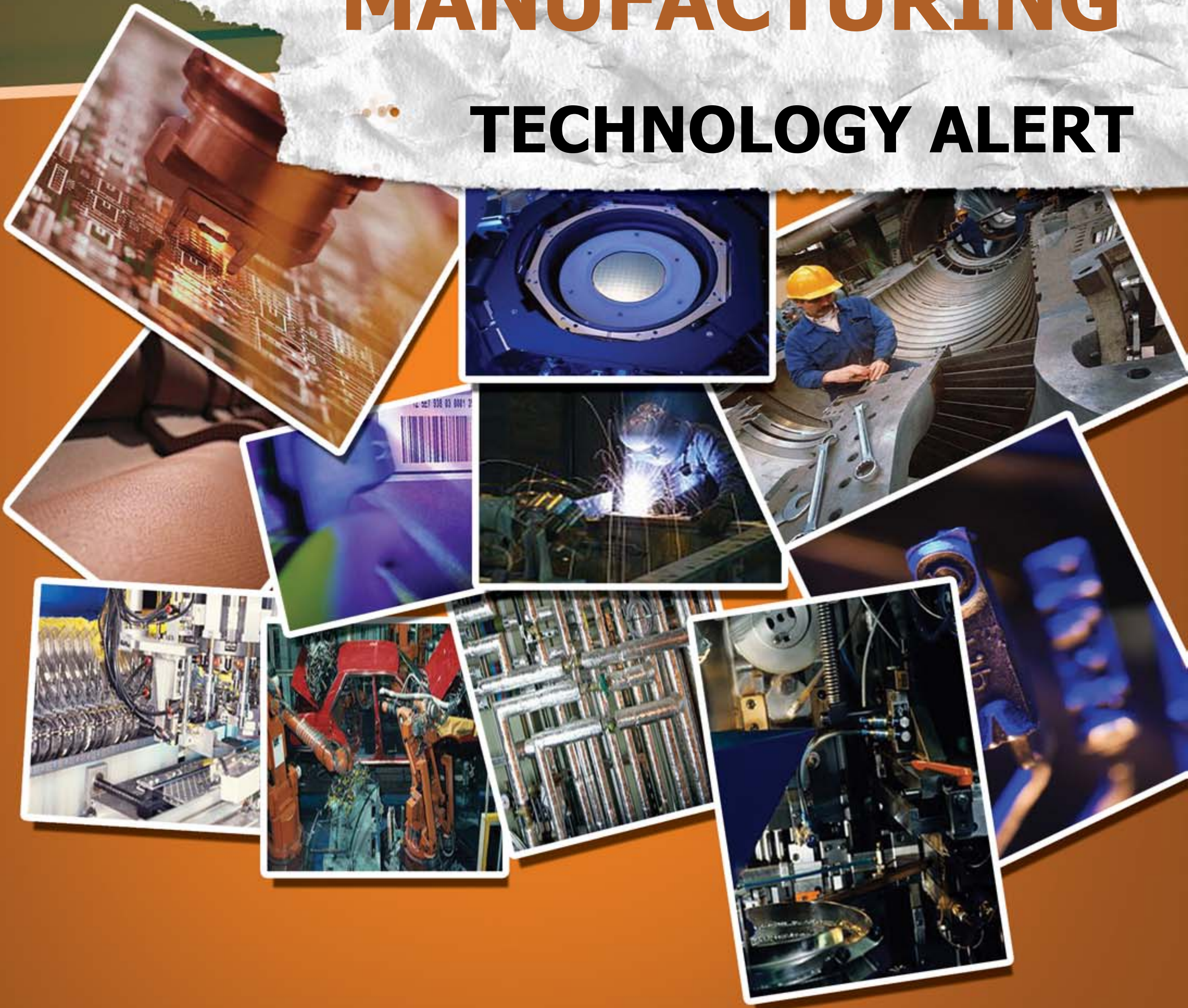
TECHNICAL INSIGHTS

ADVANCED MANUFACTURING

TECHNOLOGY ALERT



19th December 2014

1. BENEFITS OF ELECTROCHEMICAL MACHINING

The electrochemical machining (ECM) process (see exhibit), involves controlled electrochemical etching of metal articles that can precisely dissolve and remove metal in 3 dimensions (3D). One application is turbofan jet engine cases made of titanium alloy (such as Ti6Al4V). The result is a titanium alloy circular enclosure with a waffle-like pattern of reinforcing ribs, much lighter than the original work piece. Another jet engine application is machining of superalloy airfoils. This machining process (also known as reverse electroplating, or electrolysis) can be slower than high-speed metal cutting and is fairly costly, so is most appropriate for lower-volume/high-value-add difficult metal work pieces, as found in expensive jet engines.

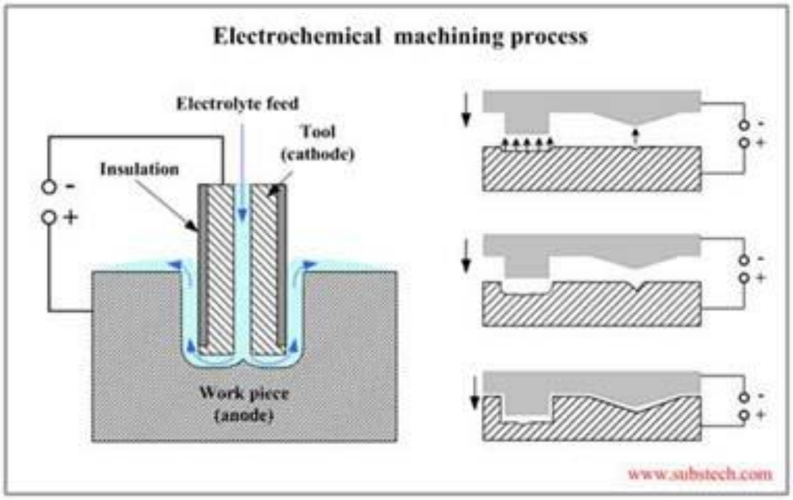


Exhibit 1 depicts the electrochemical machining process.

Picture Credit: www.substech.com

As seen in the above exhibit, ECM requires a conductive metal workpiece to serve as an anode, flooded with a conductive pressurized electrolyte. The tool is the cathode in the circuit (negatively charged), and unlike electro-discharge machining (EDM), this tool (which never touches the work piece, maintaining a gap of 0.003 to 0.030 inches) does not physically erode away. A high current is flowing between the cathode and anode, up to 5 amps per square mm. The rate of metal removal is a direct function of the current flow available. In other words, the metal removal rate (mm of depth per minute) is proportional to the amps applied per square mm. The cathode tool is shaped as a mirror image of the desired machined surface. ECM is also used to deburr or dull sharp edges on previously machined articles, working much faster than manual deburring.

ECM technology (commercially available since 1959) initially suffered from marginal dimensional accuracy; and the environmentally challenging disposal of the corrosive electrolyte. One by-product of ECM is generation of caustic sodium hydroxide, becoming entrained in the electrolyte. Both of these aspects (accuracy and waste disposal) have improved over time. Inspection of finished ECM articles shows the intricacy and complex surface topologies possible (see exhibit). Highly reflective mirror-like surface finishes are possible with this process.

Industrial and manufacturing engineers like the fact that ECM does not impart much heat nor mechanical stress into work pieces (unlike mechanical metal removal processes), and the tool material does not have to be special or more robust than the work piece metal (copper electrodes work fine). Tool wear over time is minimal. These aspects contrast sharply with other machining technologies used in the manufacturing world.

Exhibit 2 depicts the aircraft engine metal part, ECM machined.

Picture Credit: http://stankofinexpo.com/application-field/aircraft-building-aircraft-engine-industry-automobile-industry/#!prettyPhoto[gallery0]/10/

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2. CNC TURNING MACHINE ADVANCES

Technical Insights has previously written about the origin and development of revolutionary productivity-boosting computer numerical control (CNC) machine tool technology, now widespread in machine shops around the globe. This discussion will be limited to CNC turning machines, or turning centers, also known as lathes. A powerful electric motor-driven spindle secures and rotates a target metal work piece. Cutting tools, often mounted on indexable turrets, are advanced or moved toward the rotating work piece to contact and then remove metal.

With such machines, metal articles (also wood and plastics) can be turned (outside diameter [OD] reduced), bored (internal metal removal, increasing the inside diameter [ID]), threaded, cut off, as well as the performance of other fancy operations like knurling (plastically deforming/cutting the surface with special hard tooling, providing a non-slip rough surface with a uniform grid pattern). Heavy feeds for roughing get metal removed quickly. Very light feeds, with a fresh tool face, at high spindle speeds provide the desired finishing cut with exceptional surface smoothness. The key metric for surface roughness or smoothness in US machine shops is the measured root mean square (RMS) value, in micro-inches.

The current technology offered in CNC turning has come a long way from 1st and 2nd generation machines. Okuma (see exhibit), along with Yamazaki Mazak, Hyundai WIA, Doosan, Haas Automation, Amera-Seiki (among others), are prominent suppliers of state-of-the-art CNC turning centers. Spindles can be horizontal or vertical. Once the operator has programmed the CNC operations per part print (as in G code) and made sure that metal work pieces are loaded, he/she can step back, close the door, press the start button, and watch the machine perform, like magic.

Newer and more expensive CNC turning machines can add drilling and milling operations. In other words, they can effectively multi-task, saving considerable set-up time. They may also have multiple tooling turrets under electric servo control, rather than those with slower hydraulic power. They also tend to have more ergonomic tanks containing cutting fluid/coolant that are easier to handle and clean.

Such turning centers are rather expensive but very productive. If a manufacturer cannot afford such machine tools, it is recommended to outsource part production to a CNC turning specialist. In some turning operations, harmonics are induced that will set up chatter, ruining a good surface finish. One of the solutions, as practiced by Okuma, is to program the system to constantly and automatically vary spindle RPM. Exclusive to Okuma is a similar technology for threading operations. Normally, changing spindle speed while threading wrecks thread pitch, scrapping the part. Now, the operator can maintain pitch while varying the spindle speed to avoid chatter.

Exhibit 3 depicts the Okuma CNC Turning Center.

Picture Credit: https://www.apexauctions.com/auction-us/itemDetails.htm?lotId=62776

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3. ADVANCEMENTS IN 3D PRINTING

3D printing or additive manufacturing builds three-dimensional solid objects or parts by applying successive layers of materials using computer control. The objects are produced from a digital model.

Initially, 3D printing was expensive and tended to be used by large corporations to build prototypes. While prototyping remains the main application for 3D printing, improvements in 3D printing equipment and materials are enabling the technology to increasingly be used to create production parts or objects. Moreover, the increasing development and commercialization of less expensive desktop 3D printers is making 3D printing considerably more accessible to a wider range of businesses and to the general public.

A most widely used type of 3D printing material entails photopolymer resins used in, for example, stereolithograhy, digital light processing, and polyjet types of 3D printing equipment. Key types of materials now used in laser sintering include polyamide 12 and polyamide 11, also known as nylon 12 and nylon 11.

Key requirements for 3D printing materials include, for example, immunity to environmental conditions, durability, longevity, and so on. The main types of 3D printing equipment include stereolithography, laser sintering, digital light processing, polyjet, fused deposition modeling/fused filament fabrication, direct metal laser sintering, binder jet/powder bed, and electron beam melting.

Important industries for such types of 3D-printing equipment include healthcare, aerospace, automotive, and the consumer/commercial segment. Over the next 5 to 10 years, the aerospace sector is expected to become more significant for 3D printing, as evidenced by GE Aviation's plans to use 3D printing or additive manufacturing to build thousands of fuel nozzles for the Leap engine in circa 8 to 9 years or so.

Stereolithography was the initial commercialized rapid prototyping technology and has achieved widespread use. The part model is constructed on a platform positioned below the surface in a vat containing liquid, photocurable polymer (typically an epoxy or acrylate resin). An ultraviolet laser, programmed using previously created CAD (computer aided design) data, traces the first layer of the part, and scans and cures the resin within the boundaries of the outline of the slice until the entire area within the slice cross-section is solidified.

3D Systems, which invented stereolithograhy 3D printing, is the main provider of such systems. Selective laser sintering, as it was originally known, was originally created at The University of Texas, Austin. This type of 3D printing technology typically uses a carbon diode laser to provide heat to process and fuse small particles of plastic (or metal, ceramic, or glass) powders into a 3D shape.

Fused deposition modeling/fused filament fabrication equipment has been the main type of 3D printing equipment technology in terms of unit volume. Fused deposition modeling (FDM) relies on melting and selectively depositing a thin filament of thermoplastic polymer in a cross-hatching mode to form each layer of a part. A 3D object is built one layer at a time. A plastic filament or metal wire is unwound from a coil and supplies material to a heated extrusion nozzle that controls the flow. Acrylonitrile butadiene styrene (ABS) and polylactic acid

(PLA) thermoplastics are popular types of FDM/FFF materials. Stratasys has been the dominant manufacturer of fused deposition manufacturing equipment. As FDM patents have expired, more companies have entered the market with inexpensive fused filament fabrication machines. Indeed, in 2013, Stratasys acquired Makerbot, a provider of desktop fused filament fabrication 3D printers.

Less expensive desktop 3D printing machines based on laser sintering, stereolithography, or digital light processing have also been entering the marketplace.

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4. PATENT ANALYSIS OF THE ROLLING PROCESS

Rolling is a metal forming process in which the thickness of the metal stock is reduced and is made uniform by passing it through one or more pairs of rolls. Rolling can be classified into two types, hot rolling and cold rolling, based on the temperature of the metal rolled. If the temperature of the metal is above its recrystallization temperature, then the process is known as hot rolling. If the temperature of the metal is below its recrystallization temperature, then the process is known as cold rolling.

A recent patent in the rolling process, US8657970 B2, is assigned to Nippon Steel and Sumitomo Metal Corporation and pertains to a hot rolled steel sheet which has a uniform micro structure and can be easily formed into a component under conditions where a strict stretch flange processing is required.

Many patents have been filed by the following companies, JFE Steel Corporation, Sumitomo Metal Industries Ltd., Kobe Steel Ltd., and Nippon Steel Corporation, on the rolling process.

Many companies are working on new methods for manufacturing steel sheets using the rolling process. Examples include JFE Steel Corporation’s patent on a new method for manufacturing high-strength hot-rolled steel sheet (US8646301 B2) and Sumitomo Metal Industries Ltd.’s patent on a new method for producing cold rolled steel sheet (US8257517 B2).

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
Method for rolling a sheet metal strip	8 Jan 2013 / US8347681 B2	Converteam Technology Ltd.	Lionel Broussard	A method is provided for controlling cold rolling of a sheet metal strip involving continuously passing the strip in at least two successive rolling stands, each stand including at least two driven rolls between which the strip moves and is plated. The method includes estimating the slippage variation in output of one rolling stand; and correcting the rotation speed of the rolls of at least one corrected rolling stand based on the estimated slippage variation.
Method for rolling strip-shaped rolling stock, in particular metal strip	23 Jul 2013 / US8490451 B2	Sms Siemag Aktiengesellschaft	Wolfgang Denker	The invention relates to a method for rolling strip-shaped rolling stock, in particular metal strip. This method is characterized substantially by the following procedure: the metal strip A exiting the pickling line passes through the two roll stands (**3**, **4**) of the reversing roll stand, wherein the start of a subsequent metal strip B has already been welded to the strip end of the metal strip A before entering the pickling line (**5**), said start of the metal strip B is then rolled as well, specifically over a length corresponding to the wind-on length until tension is built up on the reel and likewise rims on the reversing reel (**1**), during the subsequent reversing the metal strip B is separated from the metal strip A such that the already rolled start of the metal strip B remains on the still unrolled remaining metal strip B, then the complete metal strip A is reverse-rolled.
Cold-rolled steel sheet, method for manufacturing the same, and backlight chassis	28 May 2013 / US8449699 B2	Jfe Steel Corporation	Taro Kizu, Koichiro Fujita, Eiko Yasuhara, Kazuhiro Hanazawa, Masatoshi Kumagai, Kenji Tahara, Hideharu Koga	A cold-rolled steel sheet includes, on a percent by mass basis: C: 0.0010% to 0.0030%, Si: 0.05% or less, Mn: 0.1% to 0.3%, P: 0.05% or less, S: 0.02% or less, Al: 0.02% to 0.10%, N: 0.005% or less, and Nb: 0.010% to 0.030% and the remainder composed of Fe and incidental impurities, wherein values in a rolling direction and a direction perpendicular to the rolling direction are within a range of 1.0 to 1.6, and a mean value El_m of elongations in the rolling direction, a direction at 45° with respect to the rolling direction, and the direction perpendicular to the rolling direction is 40% or more, where $El_m=(El_L+2\times El_D+El_C)/4$ and El_L: elongation in the rolling direction, El_D: elongation in the direction at 45° with respect to the rolling direction, and El_C: elongation in the direction perpendicular to the rolling direction.
Method of producing cold-rolled steel sheet	4 Sep 2012 / US8257517 B2	Sumitomo Metal Industries, Ltd.	Toshirou Tomida, Norio Imai, Mitsuru Yoshida, Kaori Kawano, Masayuki Wakita, Tamotsu Toki, Masanori Yasuyama, Hitomi Nishibata	A steel sheet excellent in mechanical strength, workability and thermal stability and suited for use as a raw material in such fields of manufacturing automobiles, household electric appliances and machine structures and of constructing buildings, and a manufacturing method thereof are provided.The steel sheet is a hot-rolled steel sheet of carbon steel or low-alloy steel, the main phase of which is ferrite, and is characterized in that the average ferrite crystal grain diameter D (µm) at the depth of ¼ of the sheet thickness from the steel sheet surface satisfies the relations respectively defined by the formulas (1) and (2) given below and the increase rate X (µm/min) in average ferrite crystal grain diameter at 700° C. at the depth of ¼ of the sheet thickness from the steel sheet surface and said average crystal grain diameter D (µm) satisfy the relation defined by the formula (3) given below: $1.2\leqq D\leqq 7$ formula (1)$D\leqq 2.7+5000/(5+350\cdot C+40\cdot Mn)^2$ formula (2)$D\cdot X\leqq 0.1$ formula (3)wherein C and Mn represent the contents (in % by mass) of the respective elements in the steel.

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
High-strength cold rolled steel sheet having excellent formability, and plated steel sheet	3 Dec 2013 / US8597439 B2	Kobe Steel, Ltd.	Shushi Ikeda, Yoichi Mukai, Hiroshi Akamizu, Koichi Makii, Koichi Sugimoto, Shunichi Hashimoto, Kenji Saito	A high-strength cold rolled steel sheet contains:0.10 to 0.28% of C,1.0 to 2.0% of Si,1.0 to 3.0% of Mn, and 0.03 to 0.10% of Nb in terms of % by mass, Al is controlled to 0.5 or less, P is controlled to 0.15% or less, and S is controlled to 0.02% or less, and residual austenite accounts for 5 to 20%, bainitic ferrite accounts for 50% or more, and polygonal ferrite accounts for 30% or less (containing 0%), of the entire structure, and a mean number of residual austenite blocks is 20 or more as determined when the random area (15 µm×15 µm) is observed by EBSP (electron back scatter diffraction pattern).
Method for cooling hot-rolled steel strip	29 Jan 2013 / US8359894 B2	Nippon Steel Corporation	Isao Yoshii, Noriyuki Hishinuma, Yoshiyuki Furukawa, Satoru Ishihara	The present invention provides a method for cooling a hot-rolled steel strip after a finishing rolling in which a transportation speed varies, the method including: setting a transportation-speed changing schedule on the basis of a temperature of a steel strip before the finishing rolling and a condition of the finishing rolling; performing a first cooling in which the hot-rolled steel strip is cooled under a film boiling state in a first cooling section; performing a second cooling in which the hot-rolled steel strip is cooled with a water amount density of not less than $2m^3/min/m^2$ in a second cooling section; and coiling the hot-rolled steel strip, in which a cooling condition is controlled in the first cooling so as to satisfy $0.8\leqq(T2\ a'-T2\ a)/\Delta Tx\leqq 1.2$.
Cooling method of hot-rolled steel strip	9 Apr 2013 / US8414716 B2	Nippon Steel & Sumitomo Metal Corporation	Yoshihiro Serizawa, Yasuhiro Nishiyama, Shigeru Ogawa, Shinji Ida, Hitoshi Nikaidoh, Isao Yoshii, Noriyuki Hishinuma, Tetsuo Kishimoto, Nobuhiro Takagi	The present invention provides a method of cooling a hot-rolled steel strip which has passed through a finishing rolling, including: cooling the hot-rolled steel strip from a first temperature of not lower than 600° C. and not higher than 650° C. to a second temperature of not higher than 450° C. with cooling water having the water amount density of not lower than 4 $m^3/m^2/min$ and not higher than 10 $m^3/m^2/min$, wherein with respect to the area of the target surface, the area of a portion where a plurality of spray jets of the cooling water directly strikes on the target surface is at least 80%.
Cooling method of hot-rolled steel strip	9 Apr 2013 / US8414716 B2	Nippon Steel & Sumitomo Metal Corporation	Yoshihiro Serizawa, Yasuhiro Nishiyama, Shigeru Ogawa, Shinji Ida, Hitoshi Nikaidoh, Isao Yoshii, Noriyuki Hishinuma, Tetsuo Kishimoto, Nobuhiro Takagi	The present invention provides a method of cooling a hot-rolled steel strip which has passed through a finishing rolling, including: cooling the hot-rolled steel strip from a first temperature of not lower than 600° C. and not higher than 650° C. to a second temperature of not higher than 450° C. with cooling water having the water amount density of not lower than 4 $m^3/m^2/min$ and not higher than 10 $m^3/m^2/min$, wherein with respect to the area of the target surface, the area of a portion where a plurality of spray jets of the cooling water directly strikes on the target surface is at least 80%.

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
Hot-rolled steel sheet excellent in fatigue properties and stretch-flange formability and method for manufacturing the same	25 Feb 2014 / US8657970 B2	Nippon Steel & Sumitomo Metal Corporation	Naoki Yoshinaga, Masafumi Azuma, Yasuharu Sakuma, Naoki Maruyama	This hot-rolled steel sheet contains, in terms of mass %, C: 0.015% or more to less than 0.040%; Si: less than 0.05%; Mn: 0.9% or more to 1.8% or less; P: less than 0.02%; S: less than 0.01%; Al: less than 0.1%; N: less than 0.006%; and Ti: 0.05% or more to less than 0.11%, with the remainder being Fe and inevitable impurities, wherein Ti/C is in a range of 2.5 or more to less than 3.5, Nb, Zr, V, Cr, Mo, B and W are not included, a microstructure includes a mixed microstructure of polygonal ferrite and quasi-polygonal ferrite in a proportion of greater than 96%, a maximum tensile strength is 520 MPa or more and less than 720 MPa, an aging index AI is more than 15 MPa, a product of a hole expansion ratio (λ) % and a total elongation (El) % is 2350 or more, and a fatigue limit is 200 MPa or more.
High-strength hot rolled steel sheet being free from peeling and excellent in surface properties and burring properties, and method for manufacturing the same	17 Apr 2012 / US 8157933 B2	Nippon Steel Corporation	Tatsuo Yokoi, Kazuya Ootsuka, Yukiko Yamaguchi, Tetsuya Yamada	This hot rolled steel contains, in terms of mass %, C: 0.01 to 0.1%, Si: 0.01 to 0.1%, Mn: 0.1 to 3%, P: not more than 0.1%, S: not more than 0.03%, Al: 0.001 to 1%, N: not more than 0.01%, Nb: 0.005 to 0.08%, and Ti: 0.001 to 0.2%, with a remainder being iron and unavoidable impurities, wherein a formula: $[Nb]\times[C]\leqq 4.34\times10^{-3}$ is satisfied, a grain boundary density of solid solution C is not less than 1 atom/nm^2 and not more than 4.5 atoms/nm^2, and a grain size of cementite grains precipitated at grain boundaries within the steel sheet is not more than 1 μm.
Method for manufacturing high strength hot rolled steel sheet	11 Feb 2014 / US8646301 B2	Jfe Steel Corporation	Takeshi Yokota, Kazuhiro Seto, Satoshi Ueoka, Nobuo Nishiura, Yoichi Tominaga	A method for manufacturing a high strength hot rolled steel sheet includes heating a slab to a temperature in the range of 1150 to 1300° C.; hot rolling the slab with a finishing rolling temperature being in the range of 800 to 1000° C.; cooling the steel sheet at a mean cooling rate of 30° C./s or higher to a cooling termination temperature in the range of 525 to 625° C.; suspending cooling for a time period in the range of 3 to 10 seconds; cooling the steel sheet in such a manner that cooling of the steel sheet is nucleate boiling; and coiling the steel sheet at a temperature in the range of 400 to 550° C.

Exhibit 4 depicts patents related to rolling.

Picture Credit: Frost & Sullivan

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