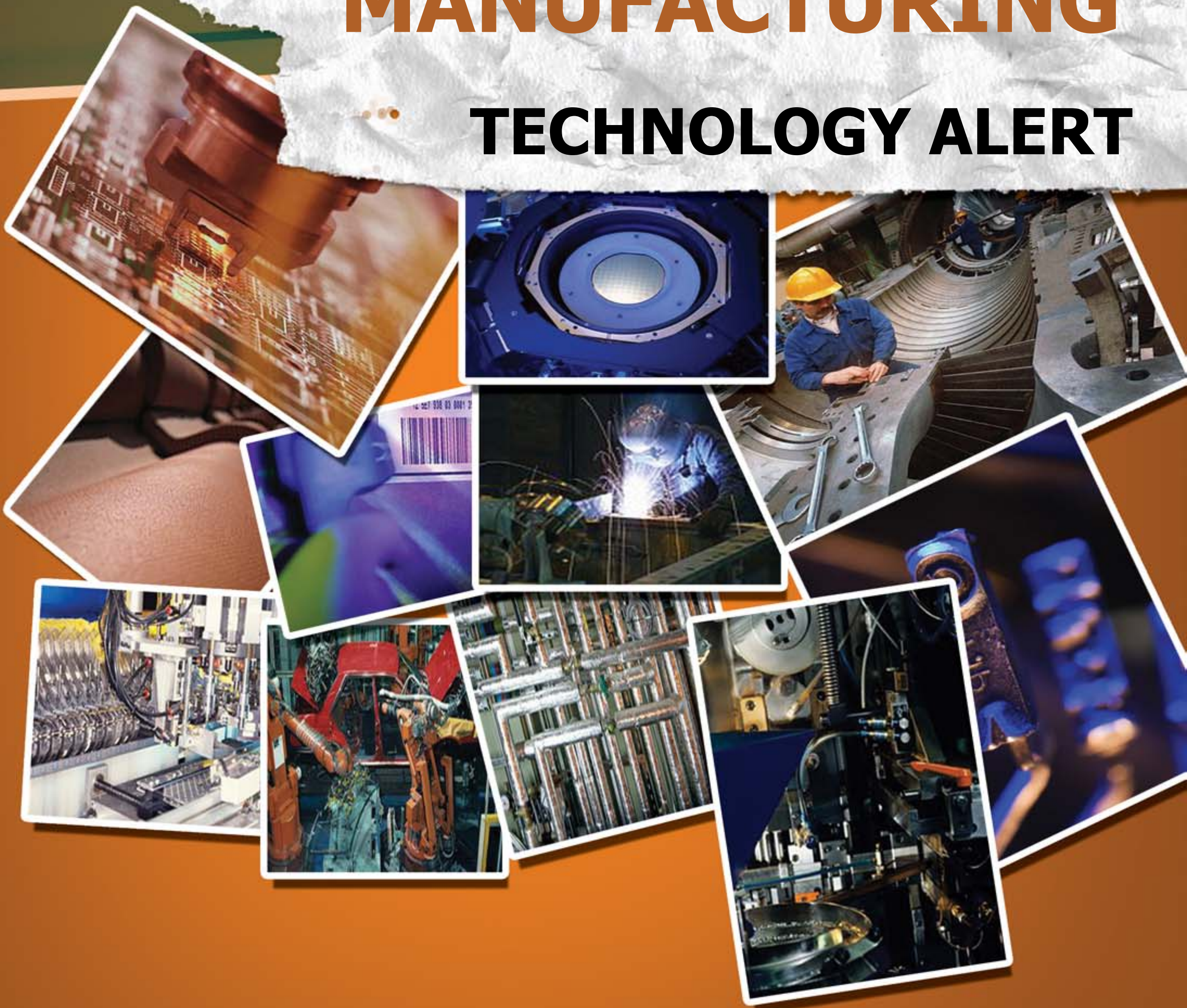
TECHNICAL INSIGHTS

ADVANCED MANUFACTURING

TECHNOLOGY ALERT



27th November 2015

1. COST-EFFECTIVE METHOD TO PRODUCE LARGE SHEETS OF GRAPHENE

Since the isolation of graphene from graphite in 2004, graphene has been considered as a wonder material. Graphene has a structure that is made up of single layer carbon atoms packed very tightly. It has been found that graphene is stronger than steel and can conduct heat and electricity very well.

Graphene has key potential in a range of applications, such as lightweight, ultra-thin, flexible, yet durable display screens; electronic circuits; solar cells; various medical (including drug delivery), chemical and industrial processes; batteries; light bulbs; and sensing (including chemical sensors, biosensors, photodetectors, Hall effect sensors, strain sensors); and so on.

Another potential opportunity for graphene entails artificial skin, where graphene of high quality and lower cost has potential to provide an ultra-flexible, conductive surface to help provide enhanced sensation in prosthetics.

Until now, graphene has been used, for example, to make several laboratory prototypes where steel, aluminum and other materials are replaced by graphene. However, large industrial-scale adoption of graphene as a replacement for other materials has been limited. This limitation is mainly due to the high costs associated with the production of graphene.

Researchers at the University of Glasgow in Scotland, led by Ravinder Dahiya of the School of Engineering at the University of Glasgow, have discovered a way to produce large sheets of graphene by using the inexpensive copper that is employed to manufacture lithium ion batteries. The researchers have been able to produce large-area graphene that is about 100 times less expensive than previously.

A key, common technique for the production of graphine entails chemical vapor deposition (CVD). In CVD, graphene is produced as tiny particles suspended in specific gas. A substrate is then introduced into the gas, where graphene deposits on the substrate to create a layer of graphene. The research team used a similar process to produce large sheets of graphene.

The researchers used ultra-smooth copper foils which are usually used in lithium-ion batteries as a substrate. For comparison purposes, the researchers also used relatively rough *'alfa aesar'* copper foil to grow graphene. Both the copper foils--ultra-smooth and alfa aesar were introduced into the CVD chamber. Calculated amounts of methane were released into the CVD chamber to keep the graphene suspended in the chamber. Graphene gradually starts to settle on the copper foils and forms a thin layer on the foils. Partial pressure and the gas flow were eventually adjusted to allow equal coverage of graphene on the copper foils. The researchers observed that the formation of a single layer of graphene on the foils is initiated with single crystal graphene formation. After the formation starts, the growth time is slowed down by keeping the methane flow constant. This ensures complete formation of the graphene layer without anomalies.

Later, to compare the quality of graphene formed, the graphene layers formed on the smooth and rough foils were transferred to a silicon oxide/silicon substrate. Raman mapping to determine the structures of smooth and rough graphene was done. The surfaces of graphene formed on the rough copper foil were observed to have longitudinal cracks. These cracks are formed due to the deep trenches present on the rough copper foil. In contrast to the rough graphene, the smooth graphene had no cracks. This means that the rough graphene is not compatible for transfer to other substrates and sensors.

Furthermore, the researchers compared the electronic properties of the graphene sheets by creating graphene field effect transistors and applying voltage across it. As the electric current passed through the rough and smooth graphene layers, it was observed that the cracks on the rough graphene can cause fluctuation in the current flow and affect its optical properties. However, the current flow through the graphene formed on smooth foil was constant. Hence, the research team foresees that the graphene formed on smooth copper can be used on microsensors and sensor arrays for gathering flawless sensing data.

As this new method of making graphene sheets uses only low-cost copper with smooth surfaces, the research team envisions that graphene can be used to make electrical optical transistors in the near future.

Details: Dr. Ravinder Dahiya, Reader, Electronics and Nanoscale Engineering, School of Engineering, University of Glascow, Glasgow, G12 8QQ, Scotland, UK. Phone: +44-0-141-330-5653. E-mail: Ravinder.Dahiya@glasgow.ac.uk. URL: www.gla.ac.uk.

2. IMPROVED VISUAL INSPECTION SYSTEM FOR FASTER DEFECT DETECTION IN ELECTRONIC PRODUCT ASSEMBLY

Visual inspection systems are state-of-the-art inspection systems that are installed in various product assemblies in industries to detect misalignments and defects much faster than human inspectors. Over time, visual inspection systems has evolved to detect defects at a minute scale, and the processing speeds have increased at a rapid pace ever since the first visual inspection systems were installed.

Recently, Fujitsu Laboratories demonstrated its latest visual inspection system which represents a key upgrade to its present line of visual inspection products. The new technology was revealed in its technology forum meeting, 'Fujitsu Forum 2015', held in Munich, Germany.

The new technology developed by Fujitsu detects misalignments and defects in production lines for electronic devices. The current technologies that detect defects in electronic production lines use complex image-processing programs. Comparisons are made with the help of image-processing programs that recognize certain geometric primitives on electronic components, such as straight lines and circles. Fujitsu has developed two technologies based on this image processing principle for automatic defect detection. The first technology compares preregistered images of parts and the whole electronic circuit board with the captured images of the components that come out of the production assembly. The comparison is then processed to detect any misalignment in the freshly made component. The second technology detects defects in various parts of electronic boards through the image recognition technique, which analyzes various features of the captured image like brightness and line orientations on electronic components.

The two technologies have now undergone a major upgrade intended to improve defect detection precision and detection speed. The previous technology developed by Fujitsu automatically generated image-processing programs to detect defects by recognizing simple geometric features such as straight lines and circles. This defect detection technology was reliable to a certain degree and performed detection as a separate process during assembly. However, for faster defect detection, this technology needs to be incorporated into the inspection process, which requires faster image-processing speeds.

Fujitsu claims the new technology will improve the existing technology for generating and evaluating images. The technology also generates visual-processing programs for the inspection process. The technology combines image-processing, machine learning and optimization capabilities of Fujitsu's proprietary technology called "Zinrai AI technology."

The two striking features of this new technology are improved misalignment detection in mounted parts and faster defect detection on electronic parts. In the earlier misalignment detection function, various parameters had to be tuned in order to avoid wrong detection of defects in parts that have similar shape. Image correction and threshold values are the most important parameters that were needed for adjustment and these adjustments were done manually. Now, in the new misalignment detection function, this tuning is automatic, increasing the speed of misalignment detection. The auto adjustment feature has been achieved by implementing a program structure that compares the image transformations of the part being detected and the whole circuit board. This program structure is based on a machine learning technique called genetic algorithms.

The defect detection process in the new technology finds defects by capturing precise values of electronic parts such as brightness, contrast, and edge orientation through a number of image transformations. Later, these values are used to build a data model and compare it with the data model of the flawless electronic part.

Details: Zhengyi Li, Researcher, Monozukuri Technologies Laboratory, Fujitsu Laboratories Ltd., Shiodome City Center, 1-5-2 Higashi-Shimbashi, Minato-ku, Tokyo, Japan, 105-7123. Phone: +81-0-3-6252-2174. E-mail: zhengyi.li@jp.fujitsu.com, fa-vision-2015@ml.labs.fujitsu.com. URL: www.fujitsu.com.

3. NOVEL METHOD TO CREATE HIGH-PERFORMANCE TRANSPARENT CONDUCTORS

Flexible and transparent electronics have been increasingly gaining popularity. This popularity can be attributed to the fact that such technologies are highly scalable and have potential applications in wearable electronics and consumer electronics. There have been many technology breakthroughs in flexible and transparent electronics that have enabled the use of flexible and transparent electronics in commercial applications.

Recently, a group of scientists from Stanford University and the Department of Energy's SLAC National Accelerator Laboratory, which is operated by Stanford University, have successfully demonstrated a method to make transparent and flexible electrical conductors. The conductors have excellent conductivity and high performance and are highly suitable for applications such as solar cells, mobile phone displays, and other microelectronic devices. The scientists have been able to achieve this feat by simply spreading certain polymers on clear surfaces using a tiny blade almost resembling the process of applying butter on a slice of bread with a knife.

The technique developed by the scientists is named "solution shearing." So far, transparent conductors are typically made from indium tin oxide (ITO). However, ITO is expensive and cannot be used with flexible displays that are being developed for next-generation displays on TVs, monitors and mobile phones. The scientists were looking for alternate materials that have characteristics that would make conductors transparent, inexpensive, and highly conductive. In search of such materials, the scientists turned to a polymer material called PEDOT:PSS poly (3,4-ethylenedioxythiophene) polystyrene sulfonate--a blend of two polymers that becomes transparent when dried and is more flexible and cheaper than ITO.

First, the scientists smeared a thin layer of PEDOT: PSS using a silicon blade of matchbook size on various materials. The materials included glass, silicon and PET (Polyethylene terephthalate)--a commonly used plastic material. The PEDOT:PSS was spread on the substrates at a speed of 6 meters per minute. Then, by adjusting the coating speed and the temperature of the process, the scientists were able to make transparent conductors of various sizes. Further, the temperature applied to the substrate separated the layers of PEDOT and PSS. The separate layers further increased the conductivity of the conductor. The new conductors had a conductivity that was higher than plain PEDOT:PSS.

After devising the process to create transparent conductors, the scientists attempted to create working electrodes using the transparent conductors. In order to make the electrodes, the scientists used the photolithography technique to print electronic circuit patterns on a glass surface. After this stage, the PEDOT:PSS polymer mixture was spread on the surface of the patterned glass with a blade. The polymer settled inside the patterns and did not settle on the glass surface. This created a circuit of conductive polymers which will conduct electric current. The resulting circuit was then used for different applications and the scientists found that the new conductive electrodes worked very well on solar cells and touch sensors.

The scientists are currently continuing their research by carrying out X-ray studies of the polymer structure to explore why spreading the polymer mixture with the blade arranges the polymer molecules in a particular orientation. The team hopes that, by knowing the reason behind the molecular arrangement, they would have an opportunity to create processes to make better transparent conductors on a large scale.

Details: Zhenan Bao, Professor of Chemistry and Professor of Materials Science and Engineering, Stanford University, 450 Serra Mall, Stanford, California 94305-2004. Phone: +1-650-723-2419. E-mail: zbao@stanford.edu. URL: www.stanford.edu.

4. EXPANDING OPPORTUNITIES FOR 3D PRINTING IN AEROSPACE

Three-dimensional (3D) printing is an additive manufacturing process in which 3D objects or structures are created from a digital file by laying down (instead of removing) successive layers of material. 3D printing, which allows for manufacturing parts without the need for intermediate tooling, provides key benefits for aerospace applications, including significant weight and fuel consumption reduction, reduced waste in manufacturing, and reduced carbon footprint. 3D printing can provide considerable savings in raw materials, such as aluminum, titanium, and nickel. 3D printing techniques allow for fabricating aerospace parts that have complex geometries, such as trussed airfoils, and can allow combining multiple components into a single part.

Initially, 3D printing has key opportunities for use in the manufacture of less critical aircraft parts, such as brackets, hinges, seat buckles, and furnishings. Over the next 5 to 10 years, 3D printing has opportunities in more critical aircraft parts, such as engines, propellers, or wings. For example, laser-based powder bed systems will be used by GE Aviation to 3D print fuel nozzles for the new CFM LEAP engines, with volume production by 2020. Besides enabling lighter weight and a streamlined design, 3D printing permits the creation of nozzles with complex internal passages, more intricate cooling pathways, and support ligaments, yielding greater durability compared to conventional manufacturing .Other jet engine parts that are promising for 3D printing include heat exchangers, piping and tubing, as well as air ducts to direct air flow, titanium parts for military aircraft, unmanned aerial vehicle structures, fasteners, connectors, knobs, trays, and panels.

In the aerospace sector, opportunities exist for 3D printing of high-temperature polymers--PEEK (polyetheretherketone), PAEK (polyaryletherketones), and PEKK (polyetherketoneketone), particularly if the cost of the material can be reduced. PAEK materials provide very good flammability and chemical resistance, low moisture sorption, good mechanical performance, good creep and fatigue resistance. However, there can be processing issues with the PEEK/PAEK family. For example, the effort required to achieve a given viscosity with heat input is much lower for a polyamide than for a PAEK material. There is a need for improved fracture toughness of PEEK powders.

Indicative of the widespread opportunities for 3D printing in the aerospace industry, researchers at Ecole Polytechnique de Montreal (Polytechnique Montreal) in Canada have been working on 3D printing of PVDF (polyvinylidene fluoride), a thermoplastic fluoropolymer with piezoelectric properties. Piezoelectric materials generate an electric charge in response to mechanical stress, or generate mechanical strain resulting from an applied electrical field. The PVDF-barium titanate nanocomposite sensors under development by the researchers could be integrated into an aerospace part to detect strain. 3D printing allows for creating a component with higher sensitivity to detect strain (or displacement) in the transverse direction, which is not possible with a flat 2D sensor. The researchers use a solvent cast 3D printing technique, developed to fabricate 3D geometries at room temperature in a freeform manner with dissolvable thermoplastic polymers. The solvent cast 3D printing process can allow creation of multifunctional microsystems with complex geometries. The ability to 3D print multiple materials (such as plastic, metal, and piezoelectric material) in the same process would allow for creating structures with added functionality. For instance, the sensor could be embedded in a handle for enhanced functionality.

Carbon fiber-reinforced composites made via 3D printing can provide higher strength and better stiffness in aero applications. There are opportunities for 3D printing of fully dense ceramic parts for applications such as turbine blades. However, carbon fiber reinforced polymers or composites need to be strong in all directions, including the Z direction.

There is interest in using fused deposition modeling to 3D print composites, such as carbon fiber-reinforced thermoplastic composites that would have improved mechanical properties in the Z direction for aero engine applications. Moreover, there are opportunities for high-temperature composites in aero engines.

For an FDM project for aero engines, the Polytechnique Montreal researchers are working on carbon fiber but are also looking at other non-conventional reinforcements. The Polytechnique Montreal researchers, furthermore, also used 3D solvent casting to fabricate a multifunctional 3D liquid sensor composed of a PLA (polylactic acid)/MWNT (multiwalled carbon nanotube) nanocomposite and shaped in a free-form helical structure. The sensor offered relatively high electrical conductivity and excellent sensitivity and selectivity. The 3D liquid helical sensor could potentially be used in aircraft hydraulic or fuel lines.

Details: Peter Adrian, Principal Analyst/Research Manager, TechVision, Frost & Sullivan, 331 E. Evelyn Avenue, Suite 100, Mountain View, CA 94041. Phone: 408-972-1865/650-475-4523. E-mail: peter.adrian@frost.com. URL: www.frost.com

5. PATENT ANALYSIS OF ELECTRON BEAM WELDING

Electron beam welding is a type of fusion welding process. In this welding method, a beam of high-velocity electrons is applied between two closely held metals that are to be joined.

When an electron beam is applied between materials, very fast moving electrons in the electron beam will hit the surface of the metals. Upon hitting the metal surface, the electrons are decelerated and the kinetic energy of each electron is transformed into thermal energy on the metal. Hence, the metal melts on both the surfaces and combines to form a strong joint. The thermal energy transformation in the electron beam welding process is nearly 90% stable. This stability is achieved because the electrons incident on the metal surfaces transfer their kinetic energy completely at any incident angle on the metal surface. This property of electron beam welding makes it more robust and reliable compared to several other welding technologies.

Exhibit 1 shows some of the patents filed for innovations in the electron beam welding process in recent times. It can be noted that most of the patents filed for electron beam welding are from organizations in China.

One of the interesting patents filed for electron beam welding belongs to Shenyang Liming Aero-Engine (Group) Corporation Ltd. (CN 104475959), pertains to vacuum electron beam welding technology for an aero-engine stator assembly. Another interesting patent is filed by Tianjin University (CN 104419884) for applying cryogenic treatment to eliminate the residual stress of titanium alloy electron beam welding joint.

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
Method of operational control of electron beam welding based on the synchronous integration method	July 1, 2015 / EP 2888070	FED STATE BUDGETED EDUCATION INSTITUTION FOR HIGHER PROFESSIONAL EDUCATION PERM NAT RES POLYTECHNIC	TRUSHNIKOV DMITRIY NIKOLAYEVICH	The invention relates to the field of electron beam welding and may be used when electron-beam welding structural materials with control and management of the power density of the electron beam directly within the welding process. The method of electron beam welding with operational control of the power density and focus level of the electron beam is differentiated by the fact that it contains stages in which: the electron beam welding is performed with a sinusoidally or linearly oscillating electron beam in the frequency range from 300 to 2,000 Hz; during the welding process, the waveform of the secondary current in the plasma is measured, filtered, and rectified. The filtered and rectified or original waveform of the secondary current in the plasma is processed using the synchronous integration method: The magnitude of the delay function, which results from processing the secondary waveform using the synchronous integration method, is measured relative to the waveform of the current in the deflection coils. The focusing current is controlled while holding the value of the delay function mentioned above at a constant level which corresponds to a specified magnitude of the power density of the electron beam.
Ultrasonic detection device and detection method for electron beam welding lines of airplane frame beam structure	June 3, 2015 / CN 104677992	BEIJING INSTITUTE OF AERONAUTICAL MATERIALS, AVIATION INDUSTRY CORPORATION OF CHINA	CORPORATION OF CHINA LIANG JING	The invention belongs to the field of nondestructive testing, and relates to a water spray type ultrasonic phased array detection device and detection method for an electron beam welding line area of an airplane frame beam structure. The detection device comprises a water collecting tank (1), a water pump (2), a control cabinet (3), a three-dimensional moving device (4), an ultrasonic flaw detector, a control computer (6), a probe clamp (7), an ultrasonic probe (8) and a hose (9). The detection device is characterized in that the ultrasonic flaw detector adopts an ultrasonic phased array flaw detector (5), and the ultrasonic probe (8) comprises a ring array ultrasonic phased array probe (8a) and a water jacket (8b). According to the detection device and the detection method, frequent probe replacement is avoided, and the detection efficiency is improved; the equipment size is reduced, and the equipment cost is reduced; the device is convenient to carry, and out-field detection is convenient.
Flexible thin-walled membranous disc module vacuum electron beam welding method	June 3, 2015 / CN 104668764	AVIC AVIATION MOTOR CONTROL SYSTEM INSTITUTE	GONG RONGQING	An engine accessory receiver and an aircraft accessory receiver are connected through a transmission shaft, and the transmission shaft is used for achieving power transfer and is known as a power take-off shaft. A membranous disc of the power take-off shaft is a flexible thin-walled part, and a weld joint is very thin. The invention provides a flexible thin-walled membranous disc module vacuum electron beam welding method for solving the technical problem. By means of the flexible thin-walled membranous disc module vacuum electron beam welding method, the problem of too large deformation of a flexible thin-walled part in the welding process is solved.

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
Manufacturing method of electron beam welding aluminum piston	May 20, 2015 / CN 104625659	CHINA WEAPON SCIENCE ACADEMY NINGBO BRANCH	HOU LINCHONG	The invention relates to a manufacturing method of an electron beam welding aluminum piston. According to the manufacturing method, a piston head part and a skirt part are independently manufactured, and a technical allowance part used for removing an arc storage air hole is reserved on the piston skirt part, so that the welding technology is simplified. The arc storage air hole of a welding seam and other defects are focused in the technical allowance part, the quality of the welding seam is guaranteed, and meanwhile the crack defects caused by different thermal stress due to uneven thicknesses of the welding seam in the prior art are overcome. According to the piston manufactured through the method, an inner-cooling oil duct is smooth, the shape is regular, the position is accurate, the yield of products is increased, and the manufacturing cost is reduced to some degree; in addition, the piston head part and the skirt part are independently manufactured, and therefore the performance of the different parts is improved, the requirements of a high-rotating-speed and high-detonation-pressure engine for the strength, abrasion resistance, heat resistance and fatigue performance of the piston are met, and the working efficiency of the piston is improved.
Stainless steel impeller welding technology and tool for electron-beam welding machine	May 13, 2015 / CN 104607849	SHANDONG SHUANGLUN CO., LTD.	ZHANG GUANGJUN	The invention discloses a stainless steel impeller welding technology for an electron-beam welding machine. The stainless steel impeller welding technology comprises the steps of punch forming, tool clamping of a rear cover plate and blades, back cover plate welding, tool clamping of a front cover plate and the blades, front cover plate welding and finish machining of a hub part ultimately. By the adoption of the technology and structure, the stainless steel impeller welding technology for the electron-beam welding machine has the advantages of being novel in structure, high in welding precision, convenient to operate, high in production efficiency, low in machining cost and the like.
Aero-engine stator assembly vacuum electron beam welding technology	April 1, 2015 / CN 104475959	SHENYANG LIMING AERO-ENGINE (GROUP) CORPORATION LTD.	GE QIN	The invention discloses an aero-engine stator assembly vacuum electron beam welding technology and belongs to the technical field of aero-engine part manufacturing. Formerly, an aero-engine stator assembly is welded through a brazing method, the brazing intensity is lower than the base metal intensity, the stator assembly performance stability is directly influenced, and a traditional welding method is excessively large in welding deformation. Compared with the prior art, after a large amount of soldering tests, the aero-engine stator assembly vacuum electron beam welding technology has the advantages that welding of the aero-engine stator assembly can be completely satisfied, brand new welding parameters are provided, the welding parameters are obtained after a large amount of welding parameter tests, welding of different thickness weld joints can be satisfied maximally, and thermal input is guaranteed uniform, the welding deformation is effectively controlled, and the requirement for stable postwelding performance of the stator assembly is satisfied due to sequence welding of the two weld joints at symmetrical positions.
CLF-1 thick steel plate electron beam welding process	March 25, 2015 / CN 104439676	NUCLEAR POWER INSTITUTE OF CHINA	CHEN LU	The invention discloses a CLF-1 thick steel plate electron beam welding process. The CLF-1 thick steel plate electron beam welding process includes the following steps of firstly, machining to-be-welded end faces of two to-be-welded CLF-1 steel plates to be smooth, and washing the to-be-welded CLF-1 steel plates; secondly, fixing the two washed to-be-welded CLF-1 steel plates, making the to-be-welded end faces of the two to-be-welded CLF-1 steel plates make contact with each other, and then placing the two to-be-welded CLF-1 steel plates in a vacuum electron beam welding machine to be welded; thirdly, conducting welding bottoming preheating on the to-be-welded end faces of the two to-be-welded CLF-1 steel plates through focusing electron beams; fourthly, conducting deep penetrating welding on the weld joint between the two to-be-welded CLF-1 steel plates through lower focal circle wave electron beams after the welding bottoming preheating is conducted; fifthly, conducting reciprocating shifting welding on the weld joint through defocusing electron beams. Due to the adoption of the two welded CLF-1 steel plates, no chain-shaped gas holes or cracks can occur at the weld joint, and the back forming effect of a welded finished product can be improved.

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
Electron beam welding and thermal processing tool and method for surface tension storage box channel	March 25, 2015 / CN 104439673	SHANGHAI INSTITUTE OF SPACE PROPULSION	YU KANG	The invention provides an electron beam welding and thermal processing integrated tool for a surface tension storage box channel. The tool comprises an outer supporting ring (1), an inner supporting ring (2), a channel positioning block (3), a channel pressing block (4), a pressing block supporting plate (5), a pressing plate threaded rod (6), a screw connecting sleeve (7) and screws. The outer supporting ring (1) is connected with the inner supporting ring (2) through the corresponding screw. The outer supporting ring (1) is connected with the channel pressing block (4) through the pressing plate threaded rod (6) and the screw connecting sleeve (7). The channel pressing block (4) is connected with the pressing block supporting plate (5) through the corresponding screw. The channel pressing block (4) is connected with the channel positioning block (3) through the corresponding screw. The inner supporting ring (2) is connected with the channel positioning block (3) through the corresponding screw. Thermal processing can be directly conducted without detaching the tool after electron beam welding is conducted, the channel less deforms, the breakage probability of a stainless steel net is lowered, and the product percent of pass is increased.
Application of cryogenic treatment in eliminating residual stress of titanium alloy electron beam welding	March 18, 2015 /CN 104419884	TIANJIN UNIVERSITY	XU LIANYONG	The invention discloses an application of cryogenic treatment in eliminating residual stress of titanium alloy electron beam welding. According to the application disclosed by the invention, after electron beam welding is finished, the cryogenic treatment is directly carried out without treating a welding joint, wherein the liquid nitrogen temperature ranges from 185 DEG C below zero to 196 DEG C below zero. A cryogenic treatment method is capable of effectively lowering the residual stress of a titanium alloy electron beam welding joint; compared with the other treatment method, the cryogenic treatment method is simple to operate, is environmentally friendly in process and is also capable of improving the tissue of the joint and the size stability.
Electron beam welding method using backing thin plate	March 16, 2015 /KR 1020150028511	Hyundai Heavy Industries Co., Ltd.	SUNG, HEE JOON	The present invention relates to an electron beam welding method using a backing thin plate, comprising: a step of mounting and tack welding a welding workpiece to be welded; a step of stacking and attaching a plurality of backing thin plates on the back side of a welding part of the welding workpiece; a step of placing the welding workpiece inside a vacuum chamber, and creating vacuum in the vacuum chamber; a step of provisionally welding the welding part of the welding workpiece; a step of focusing an electron beam on the welding part of the welding workpiece and melting the welding part; a step of releasing vacuum of the vacuum chamber and removing the vacuum chamber; and a step of removing the backing thin plate from the back side of the welding part of the welding workpiece. As a plurality of backing thin plates are stacked, even if a welding workpiece is stuck to a backing thin plate by meltdown, backing thin plates except for a thin backing plate adjacent to a welding workpiece can be easily separated. Moreover, the thin backing plate adjacent to the welding workpiece can be easily removed by using a grinder after being cut by a laser as the thickness thereof is thin. The present invention has an effect of increasing productivity by reducing costs and labor time by performing attaching work without a step performed to be suitable for the shape of a welding part when a backing thin plate is used as a welding backing material of a ship material wherein a plurality of curved panels and circular pipes or the like are used, as the thickness of the backing thin plate is 3-6 mm and thin in comparison with a backing material with a typical thickness. COPYRIGHT KIPO 2015

Exhibit 1 depicts patents related to electron beam welding.

Picture Credit: Frost & Sullivan

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